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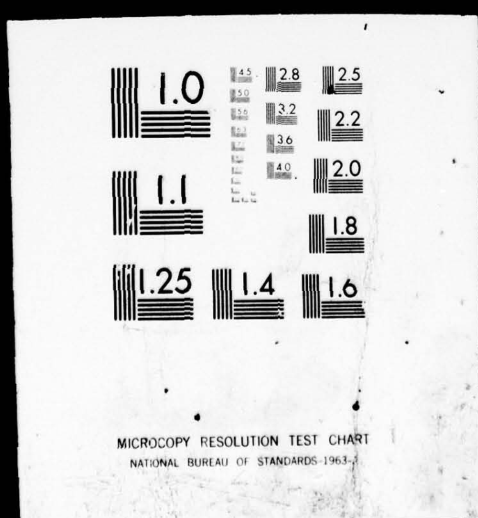

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the Faculty of the School of

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In Partial Fulfillment

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by

Maurice A. Roesch III

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The opinions expressed here are those of the author and do not necessarily reflect the views of the Department of Defense, any specific military service, or any individual within the Defense establishment

ABSTRACT

This dissertation investigates the management of systems-acquisitions for the Department of Defense (DOD). It indicates how the DOD can apply systems-engineering techniques for a more effective approach to decisions involved in developing and procuring DOD systems.

Based on an analysis of the existing policy structure of the DOD for acquiring new systems, a model is developed for the activities and major-decision points of that system's acquisition process using various phases and steps of systems-engineering methodology. The nature and the structure of the decision process provide specific areas where a systems-engineering methodology could be applied most beneficially. After the criteria are established for choosing the appropriate systems-engineering tools and techniques, a methodology is developed with specific analysis procedures dependent on the stage of the acquisition process and the nature of the decision under consideration. A systems-engineering team with specific functions and characteristics is suggested as a means by which the methodology is implemented.

To support the conclusion that a systems-engineering methodology can be successfully applied to the decisions involved in acquiring DOD systems, a DOD systems-acquisition program is analyzed in a historical context. The program analyzed is orietnted toward the development of a tactical intelligence system. This analysis indicates how a systems-engineering approach and a systems-engineering team may be beneficially applied to real-world acquisition problems.

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EXECUTIVE SUMMARY

Background

During the late 1960's and early 1970's, systems-acquisition efforts within the Department of Defense (DOD) were beset with a number of significant problems. In 1969, the General Accounting Office (GAO) conducted a survey of thirty-eight major weapons-systems programs and found projected costs-to-completion 15 percent higher than the original contract cost figures. In particular two aircraft-acquisition programs, the C-5A and the F-111 programs, had received a good deal of unfavorable public attention. Operational requirements for the C-5A program were overspecified, which limited design trade offs and led to significant cost overruns. The F-111 fighter program experienced technical problems and unprecedented cost growth from approximately $3 million per unit in 1966 to almost $15 million per unit in 1970. These problems were caused by a variety of factors, including ineffective program management on the government's part, poor DOD/contractor relationships, over centralization of systems-acquisition management within the Office of the Secretary of Defense (OSD) and poorly defined operational requirements.

In 1969 the new Republican administration came into office with Melvin Laird as Secretary of Defense and David Packard as his Deputy. Both Laird and Packard viewed what

they found in the Defense systems-acquisition area with alarm. It was clear that a major reorganization of the systems-acquisition process was required. Mr. Packard, the official responsible for all Defense research, development, and procurement, assumed this task.

In May 1969, Packard established the Defense Systems Acquisition Review Council (DSARC), which represented a management system for major Defense systems acquisitions. The mission of the DSARC was "to review major and important Department of Defense systems-acquisition programs at appropriate milestone points in their life cycle." Top-level DOD managers were to sit on this board, review and evaluate the programs, deliberate among themselves on program alternatives presented by the services, and make recommendations to the Secretary of Defense on the various program alternatives. In addition to establishing the DSARC, Packard also implemented several other revisions to the systems-acquisition process, including development of decentralized management guidelines, clarification of OSD responsibilities, adoption of the "fly-before-you-buy" concept, formal publication of new acquisition policies and encouragement of new contracting procedures.

During this same period of time, procurement policies of the overall federal government had also come under close scrutiny. In the early 1970's the Commission on Government Procurement studied these policies and issued a report in

1972 that documented a number of recommendations in this area. These recommendations have evolved into a revised set of procurement policies presented in OMB Circular A-109, *Major Systems Acquisition*, which was issued by the Office of Federal Procurement Policy on April 5, 1976.

Circular A-109 defined a major system as "that combination of elements that will function together to produce the capabilities required to fulfill a mission need." Major programs are those that "are directed at and critical to fulfilling an agency mission, entail the allocation of large resources and warrant special management attention." The A-109 directive was developed to set forth policies in several key areas as follows: the strengthening of the program-management function, communication with Congress early in the acquisition process, the designation of an acquisition executive for each agency, the expression of needs in mission terms, the exploration of alternative systems, and the reservation of four major program decisions for the agency head.

The DOD has directed the implementation of the policies of A-109 with two directives, 5000.1 (*Major Systems Acquisitions*) and 5000.2 (*Major Systems Acquisition Process*), which were issued in January 1977. These directives established an overall DOD systems-acquisition-policy framework and defined a major systems-acquisition program as one that has a projected research, development, test, and evaluation (RDT&E) cost of $75 million or a projected procurement cost

of $300 million. In keeping with the policies of A-109, the directives reserved four key major-program decisions for the Defense agency head (Secretary of Defense):

1. *Milestone 0* - Decision for Program Initiation (approval of need and advancement to conceptual phase);

2. *Milestone I* - Decision to Proceed to Demonstration and Validation;

3. *Milestone II* - Decision to Proceed to Full-Scale Development;

4. *Milestone III* - Decision for Production and Development.

In accord with the policies originally established by Deputy Secretary of Defense Packard, the DOD directives required the establishment of the Defense Systems Review Council (DSARC) with a membership of top-level-DOD managers and responsibility to review major programs and make recommendations to the Secretary of Defense prior to major decision milestones I, II, and III. These DOD directives also established the (Service) Systems Acquisition Review Council ([S]SARC) with a membership of top-level managers at the service headquarters. A (S)SARC was established at each service headquarters to review major programs and make recommendations to each service secretary for the decision process at milestones I, II, and III prior to consideration of the program by the DSARC and Secretary of Defense.

The DOD directives also required that two separate documents be developed for each major program. The Mission Element Need Statement (MENS) is used to document the mission need and includes a statement of the need in terms of mission-element tasks, a projection of the enemy threat, an identification of the existing DOD capability to accomplish the mission, a listing of constraints for the problem, and a program plan to identify and explore competitive alternative systems. The Decision Coordination Paper (DCP) is developed or updated prior to milestones I, II, and III. It includes a number of program considerations, including the updated MENS, acquisition strategy, business plan, management plan, areas of program uncertainty, resources required, test-and-evaluation plan, program issues, DSARC and (S)SARC recommendations, and Secretary of Defense decisions and directions. These documents play key roles in the systems-acquisition process and in the operations of the DSARC and (S)SARCs.

Analysis of Organizational Goals

The DSARC reflects the value system operative within DOD related to the systems-acquisition process when it pursues its primary (top-level) goal of "to acquire a set of Defense capabilities which are adequate to implement national policies." Several DSARC subgoals contribute to accomplishing this top-level goal, including to be responsive to the lead of Congress, to be guided by the directives and

policies of the executive branch, to be concerned for a viable defense industry, to foster effective systems-acquisition-management capabilities, to be concerned for international security matters, and to develop the best overall program of systems acquisitions. The (S)SARCs have a similar set of goals except that each also assumes the role of "advocate for the institutional values of each pa-ticular service."

In pursuing the upper level goal of developing best overall program of systems acquisitions," the DSA the (S)SARCs consider other subgoals, which contribute ts accomplishment. These subgoals are: to insure only t ini-mum set of systems-acquisition programs necessary to eet national-defense requirements are approved, to induce a flexible approach to major systems acquisitions, to minimize systems-development time, to induce standardization and interoperability, to insure that MENS and DCP are fully developed and properly documented, and to identify critical issues and evaluation factors for each program. All of these subgoals are important in the systems-acquisition decision process. These goals are presented on the attached illustration.

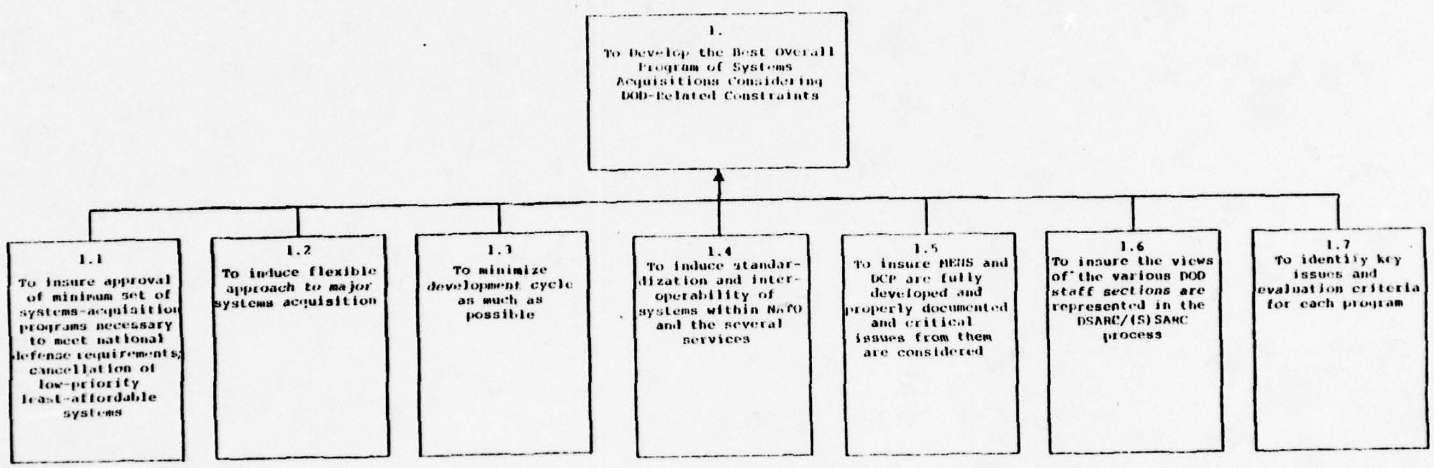
Problem Definition

This systems study addressed the possibility of developing a systems-engineering methodology to support the systems-acquisition decision process. A problem definition for this study is:

ILLUSTRATION A

Objectives Tree for the Value System Operating in the DSARC/(S)SARC Groups.

$\uparrow \Rightarrow$ Will contribute to the accomplishment of



To determine how the Defense systems-acquisition process may be improved using the techniques of systems engineering. The emphasis of this study is directed toward the four major-decision milestones (0, I, II, and III), the operation of the DSARC and (S)SARC advisory boards, and the use of the Decision Coordination Paper (DCP) and Mission Element Need Statement (MENS) within the overall DOD-policy framework.

Results of the Analyses

It is demonstrated that there is a respective pairwise relationship between phases and activities of the systems-acquisition process and the phases and steps of the systems-engineering framework (Illustrations B and C). The systems-acquisition process and systems engineering are also comparable in that both require multidisciplinary efforts if they are to be carried out effectively.

DOD personnel currently involved in the system-acquisition process often do not view the process in the context of the systems-engineering framework. Many do not see the overall comparison between the systems-acquisition process and a systems-engineering framework. They do not perceive the parallelism between the several phases of the systems-acquisition process with their comparable activities and decision points. This is particularly true of the

ILLUSTRATION B

THE TIME-DIMENSION PHASES OF THE SYSTEMS-ENGINEERING MORPHOLOGY COMPARED TO THE PHASES OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Time-Dimension Phases	Systems-Acquisition Life-Cycle Phases
Program planning	Mission analysis and development of MENS
Project planning	Conceptual Demonstration and validation
System development	Full-scale development
Production	Production
Distribution	Deployment or phase in
Operation	1. Operation/support 2. Maintenance/repair 3. Modification/retrofit
Retirement	Retirement or phase out

ILLUSTRATION C

COMPARISON OF THE LOGIC-DIMENSION STEPS OF THE SYSTEMS-ENGINEERING MORPHOLOGY WITH THE ACTIVITIES OF THE FOUR PHASES OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Logic-Dimension Steps	Systems-Acquisition-Phase Activities			
	Mission Analysis	Conceptual	Demonstration and Validation	Full-Scale Development
Problem definition	Mission need identification	Define acquisition problem	Define systems problem	Define production problem
Value-system design	Identify mission need in terms of mission *element*	Identify program goals and objectives	Examine and validate program goals and objectives	Examine and validate program goals and objectives
System synthesis	Identify known-solution candidates	Identify candidate-system alternatives	Validate and refine system or program alternatives	Validate projected system alternatives
Systems analysis and modelling	Develop enemy-threat scenarios for time frame of required capability	Develop models to evaluate operational consideration, acquisition approaches	Develop models to evaluate system or program alternatives	Develop models to evaluate projected system
Optimization	Assess impact of not acquiring or maintaining capability	Evaluate candidate-system alternatives	Evaluate system or program alternatives	Evaluate full-scale development model
Decision making	*Milestone 0* (MENS approval cycle)	*Milestone I* (DCP approval cycle)	*Milestone II* (DCP approval cycle)	*Milestone III* (DCP approval cycle)
Planning for action (implementation of next phase)	Implementation of conceptual phase	Implementation of demonstration-and-validation phase	Implementation of full-scale-development phase	Implementation of production-and-deployment phase

mission-analysis (program-planning) phase of the systems-acquisition process as compared to the other phases.

Using the systems-engineering framework, it was determined that the systems-acquisition process is a *stage-approach* problem having several sequential stages. A stage is a period of time wherein specific objectives of a reasonably well-defined R&D effort are pursued and that has a well-defined decision point associated with the effort. Each stage of the process may be characterized by four factors:

1. Clear boundaries;
2. progressively decreasing risk and uncertainty;
3. progressively increasing investment;
4. increasing time required for completion of the stage.

The *stage-approach* nature of the systems-acquisition process suggests the need for several program-related criteria for choosing appropriate systems-engineering tools and techniques: (1) quantity and quality of available data, (2) risk and uncertainty associated with the program during each phase, (3) program objectives, (4) the systems-engineering logic-dimension step being analyzed, and (5) resource requirements of the program.

Several organizational considerations also affected the nature, type, and degree of analysis that should be

included in a systems-engineering methodology to support decision making for the systems-acquisition process: (1) the predisposition of an organization to use analysis procedures, (2) the position of the analysis unit within the organizational hierarchy, (3) the background and experience of the decision makers, (4) the availability of the decision makers, (5) the mechanism used to transfer results of an analysis to the decision makers, (6) criticality of the decision to an organization, (7) the availability of resources for the analysis process, and (8) the mode of organizational operation.

Considering the systems-engineering framework and the stage-apporach nature of the systems-acquisition process, the following analysis areas where the application of a systems-engineering methodology would be most beneficial are: The development of the Mission Element Need Statement (the problem definition in the program-planning phase) and the provision for decision support at Milestones 0, I, II, and III. Unified Program Planning is used in the development of the MENS; justification (viability/objectives) checklists, project-scoring models, and the multiattribute utility theory are selected as the decision-support analysis procedures for Milestones 0, I, II, and III, respectively. The analysis procedures associated with the development of the MENS and the provision to support the necessary decisions

for the four major-decision milestones constitute the systems-engineering methodology for the systems-acquisition decision process.

Implementation of Methodology

The implementation of the methodology would be carried out by the development and proper use of systems-engineering teams located within the research and development (R&D) staff section of each service headquarters and within the OSD. These teams are motivated by the need *to bridge the gap* between other analysis and engineering groups within and external to the organization and the various policymakers and decision makers of the organization. In the case of the systems-acquisition process, the policymakers and decision makers are represented by the Secretary of Defense, the service secretaries, the DSARC members, and the (S)SARCs members.

Members of these multidiscipline teams should possess graduate-level education in systems engineering, be mature and experienced as analysts, possess operational or management experience, be out-going in their professional relationships, be trustworthy, and be innovative. The team manager should be particularly strong in these characteristics. There are several general functions the teams should perform; they should be cognizant of on-going analysis procedures, monitor and assist in the choice and implementation of standardized

analysis procedures, advise management on overall analysis policies, bilaterally translate information flowing between analysis groups and policy/decision makers, and assist and advise policy/decision makers relative to both the choice of methodology and the interpretation of results obtained using the systems methodology.

The systems-engineering teams would have specific functions within DOD as follows: To assist DOD in developing an overall systems-acquisition-analysis policy, assist in implementing systems-acquisition-analysis policies and methodologies, assist in preparing for DSARC and (S)SARC major-decision milestones, and assist in the development of the actual analysis structure for selection and evaluation of major-systems programs. The members of the systems-engineering teams would work closely with the DOD policymakers and decision makers in carrying out these functions.

Costs

There would be several costs associated with implementing the methodology. The primary cost would be to establish an engineering group of approximately twenty-five professional personnel within the OSD and within the R&D staff sections of each of the services' headquarters. These groups would be divided into teams of approximately five people, each of which would be capable of supporting the four or five systems-acquisition programs that would be

under consideration during any specific period. Each systems-engineering group would require appropriate technical and administrative support to carry out their functions. A second cost would be the additional management time required of decision makers and policymakers to effectively implement the more rigorous decision process associated with the systems-engineering methodology. The final cost would be for the necessary revisions to policies and procedures within DOD associated with the implementation. However, these revisions would not be significant.

Benefits

The implementation of the systems-engineering methodology should provide several benefits to DOD: A better defined, more highly structured set of Defense systems-acquisition problems; a more equitable evaluation process for all programs due to standardized analysis procedures; the improved ability for decision makers to discriminate between development alternatives and whether or not to continue the programs. The formation and proper use of the systems-engineering teams would provide decision makers and policy makers a means by which they could enhance their managerial abilities. This enhancement would be realized by the improved communications between decision makers and the various analysis groups working on the programs.

A historical analysis is presented for the Marine Air/Ground Intelligence System (MAGIS) acquisition program for the period 1972 to 1975. This program is oriented toward the development of a tactical intelligence system. In 1972 the MAGIS program had several development problems associated with it, including parallel development efforts to acquire basically the same operational capabilities, a lack of standardization of hardware and software design, a potential for interoperability problems for several segments of the system, and the lack of a global operational concept for the employment of the system once it was developed.

The need to develop a multidisciplinary engineering group to address the MAGIS acquisition program was identified in October 1972. As a result, during early 1973 a systems-engineering team was formed to assist in developing MAGIS. Over the next two and a half years, this team *bridged the gap* between Headquarters Marine Corps policy and decision makers and the various analysis and engineering groups working on the program.

The MAGIS systems-engineering team worked closely with Headquarters Marine Corps' decision makers on several key activities and decision points, including the development and approval of an overall operational concept for the system; the development and approval of a new acquisition approach for the system, which eliminated parallel development efforts; the support for an In-Progress Review Committee decision on the

program; and the support for the Marine Systems Acquisition Review Council, Milestone II decision for the system. The significant benefits derived from the employment of the systems-engineering team on the MAGIS program are the elimination of parallel development efforts with a projected cost savings of over $20 million, the provision for a means by which decision makers and policy makers could more effectively carry out their responsibilities, and the provision of a means by which the decisions of Headquarters Marine Corps could be more effectively transmitted to the various analysis and engineering groups working on the program.

Conclusions

Based on the material developed in this systems study, several conclusions may be drawn. Four major conclusions are presented here in priority order.

1. The systems-acquisition process may be effectively modelled by a systems-engineering framework. The two are similar in that there is a respective pairwise correlation between the phases and steps of the framework and the phases and activities of the process. Additionally, both the systems-acquisition process and systems engineering are multidisciplinary activities.

2. The systems-acquisition process could benefit from the application of a systems-engineering methodology to support (1) the problem definition in the mission-analysis phase, and

(2) the major-decision milestones of the process. The analysis techniques selected as procedures in the methodology should be dependent on both organizational considerations and the stage of the development program under evaluation.

3. Effective implementation of the methodology is critically dependent on the formation and proper use of systems-engineering teams working with to-level managers within the Office of the Secretary of Defense and the several service headquarters. The principal role for these teams is that of *bridging the gap* between policy makers and decision makers and the various analysis and engineering groups working on the program. In this role, they can significantly enhance communications for the development programs and thereby improve the overall management of the systems-acquisition process. These improvements would be reductions in research, development, test and evaluation, and production costs and in development time; they would enhance supportability and interoperability once the system is deployed.

4. The systems-engineering team associated with the Marine Air/Ground Intelligence System (MAGIS) development program (selected for historical analysis) *bridged the gap* between Marine Corps Headquarters (policy and decision makers) and the several analysis groups working on the program. The employment of the systems-engineering team in this role provided substantial benefits to the Marine Corps from 1972 to 1975 and is a good example of the successful application of the methodology, which is the subject of this dissertation.

Recommended Actions

It is recommended that the systems methodology and associated analysis procedures developed in the study be applied by DOD to a variety of active systems-acquisiton programs. This recommendation includes the establishment of the several systems-engineering teams as suggested in the study. Several other possible actions that the federal government may want to pursue are:

1. To extend the systems-engineering-methodology tasks to other activities of the DOD systems-acquisition process.

2. To establish criteria to determine the applicability of a systems-engineering methodology to the systems-acquisition process within other federal agencies.

3. To develop a specific systems-engineering methodology to support the systems-acquisition decision process in other federal agencies, such as, the Department of Transportation or the Department of Energy.

4. To develop a global systems-engineering methodology to support the systems-acquisition decision process for all federal agencies from the perspective of the Office of Federal Procurement Policy within the Office of Management and Budget.

5. To research the areas of interaction between the federal government and the industrial sector in relation

to the application of a systems-engineering methodology to the systems-acquisition decision process.

ABBREVIATIONS AND ACRONYMS

A-109	OMB INSTRUCTIONS ON SYSTEMS ACQUISITION
ADM	ADVANCED DEVELOPMENT MODEL
AFR	AIR FORCE REGULATION
AFSC	AIR FORCE SYSTEMS COMMAND
AMC	ARMY MATERIAL COMMAND
ANMB	ARMY/NAVY MUNITIONS BOARD
AR	ARMY REGULATION
ASARC	ARMY SYSTEMS ACQUISITION REVIEW COUNCIL
CAIG	COST ANALYSIS IMPROVEMENT GROUP
CGP	COMMISSION ON GOVERNMENT PROCUREMENT
CIA	CENTRAL INTELLIGENCE AGENCY
DAE	DEFENSE ACQUISITION EXECUTIVE
DCP	DECISION COORDINATING PAPER
DEPSECDEF	DEPUTY SECRETARY OF DEFENSE
DDR&E	DIRECTOR DEFENSE RESEARCH AND ENGINEERING
DIA	DEFENSE INTELLIGENCE AGENCY
DOD	DEPARTMENT OF DEFENSE
DSARC	DEFENSE SYSTEMS ACQUISITION REVIEW COUNCIL
DT	DEVELOPMENT AND TEST
DT&E	DEVELOPMENT TEST AND EVALUATION
FYDP	FIVE-YEAR DEFENSE PLAN
GAO	GENERAL ACCOUNTING OFFICE
GERT	GRAPHICAL EVALUATION AND REVIEW TECHNIQUE
GOR	GENERAL OPERATIONAL REQUIREMENT

HQMC	HEADQUARTERS, MARINE CORPS
IAC	INTELLIGENCE ANALYSIS CENTER
IA/SR	INTELLIGENCE ANALYSIS STORAGE AND RETRIEVAL
II	IMAGERY INTERPRETATION
IOC	INITIAL OPERATIONAL CAPABILITY
IOT&E	INITIAL OPERATIONAL TEST AND EVALUATION
IP	IMAGERY PROCESSING
IR&D	INDEPENDENT RESEARCH AND DEVELOPMENT
JPL	JET PROPULSION LABORATORY
LCC	LIFE CYCLE COSTS
MAGIS	MARINE AIR/GROUND INTELLIGENCE SYSTEM
MBT	MAIN BATTLE TANK
MCDEC	MARINE CORPS DEVELOPMENT AND EDUCATION COMMAND
MENS	MISSION ELEMENT NEED STATEMENT
(M)SARC	MARINE SYSTEMS ACQUISITION REVIEW COUNCIL
MS/OR	MANAGEMENT SCIENCE/OPERATIONS RESEARCH
NDAC	NATIONAL DEFENSE ADVISORY COMMISSION
NMC	NAVAL MATERIAL COMMAND
NSA	NATIONAL SECURITY AGENCY
ODCSRDA	OFFICE OF THE DEPUTY CHIEF OF STAFF FOR RESEARCH DEVELOPMENT AND ACQUISITION
OFPP	OFFICE OF FEDERAL PROCUREMENT POLICY
OMB	OFFICE MANAGEMENT AND BUDGET
O&M	OPERATION AND MAINTENANCE
OPM	OFFICE OF PRODUCTION MANAGEMENT
OSD	OFFICE OF THE SECRETARY OF DEFENSE
OT&E	OPERATIONAL TEST AND EVALUATION

PERT/CPM	PROGRAM EVALUATION AND REVIEW TECHNIQUE/CRITICAL PATH METHOD
POM	PROGRAM OBJECTIVES MEMORANDUM
PPBS	PLANNING, PROGRAMMING, AND BUDGETING SYSTEM
R&D	RESEARCH AND DEVELOPMENT
RDT&E	RESEARCH, DEVELOPMENT, TEST AND EVALUATION
RFP	REQUEST FOR PROPOSAL
ROIS	REMOTE INPUT/OUTPUT SYSTEM
SECDEF	SECRETARY OF DEFENSE
SECNAV INST	SECRETARY OF THE NAVY INSTRUCTION
SERVSEC	SERVICE SECRETARY
S/EWCC	SIGNAL INTELLIGENCE/ELECTRONIC WARFARE COORDINATION CENTER
SOR	SPECIFIC OPERATIONAL REQUIREMENT
(S)SARC	(SERVICE) SYSTEMS ACQUISITION REVIEW COUNCIL
T&E	TEST AND EVALUATION
TERPE	TACTICAL ELECTRONIC RECONNAISSANCE PROCESSING AND EVALUATION
TIPI	TACTICAL INFORMATION PROCESSING AND INTERPRETATION
TRADOC	TRAINING AND DOCTRINE COMMAND
TSOR	TENTATIVE SPECIFIC OPERATIONAL REQUIREMENT
VSTOL	VERTICAL AND SHORT TAKE OFF AND LANDING
WPB	WAR PRODUCTION BOARD
WRB	WAR RESOURCES BOARD
WoPAST	WORK PLAN ANALYSIS AND SCHEDULING TECHNIQUE
5000.1 5000.2	DOD DIRECTIVES ON MAJOR SYSTEMS ACQUISITION

Chapter 1

BACKGROUND ON THE SYSTEMS-ACQUISITION PROCESS OF THE DEPARTMENT OF DEFENSE

Introduction

Since World War II, research and development (P&D) within the United States has grown to be an industry of major proportion. United States government expenditures for all R&D categories have increased from less than $78 million in 1940 (Perlman, 1963) to a projected total of $25.7 billion for 1979 (Mosbacker, 1979). Nonfederal R&D has increased from $2.4 billion in 1954 (Head, 1974) to a projected total of $26.1 billion for 1979 (Mosbacker, 1979). The growth of defense-related R&D has also been significant, with $12.7 billion budgeted for fiscal year 1979 (Aviation Week Staff, 1979). The cost growth in R&D and the increasing complexity of technology can be measured by comparing R&D costs to overall program costs for several systems: R&D was one percent of the total program costs (R&D, investment, and operation) for the F-86 Saberjet in the late 1940's, 24 percent of the total program costs for the Polaris Fleet Ballistic Missile Program during the 1950's and 1960's, and 38 percent of the total program costs for Sweden's System 37 Viggen during the 1970's (Head, 1974).

In addition to the problems of R&D cost growth and the increasing complexity of the technological base, the

world has significantly changed since 1940. First, World War II made it clear that air, ground, and sea warfare cannot be autonomous functions. Rather, these entities must be effectively integrated if success at modern warfare is to be achieved. Secondly, the world has entered the atomic age with all its attendant strategic implications. Thirdly, Russia has emerged as a superpower and the North Alantic Treaty Organization (NATO) has evolved to counter this threat. All these changes have required revisions in the way that national defense is managed and that military systems are acquired. How these revisions have come about since World War II is the subject of this chapter.

World War II

During World War II, the United States spent more than $315 billion on military procurement, production, and construction. From early 1940 until the war's end in 1945, the delivery of weapons, equipment, and supplies to the armed services cost over $162 billion. Many weapons systems were developed separately by the War Department (Army and Army Air Corps) and Navy Department (Navy and Marine Corps), including aircraft carriers, battleships, tanks, and various aircraft. However, the production, support, and operations were coordinated among the several military services (Smith, 1959).

Weapons-systems procurement and the war-planning function for the armed services were coordinated on a national level by several different boards and agencies (Birdsell, 1976): the Army/Navy Munitions Board (ANMB), the War Production Board (WPB), the Office of Production Management (OPM), the National Defense Advisory Commission (NDAC), and the War Resources Board (WRB). The War Department had its own agency for the control and direction of procurement--the Army Service Forces; the Navy Department also had an agency for procurement and logistic matters--the Naval Office of Procurement and Material. These various agencies, which were necessary for managing the overall war effort, were also effective in national planning and procurement. By 1945 it was clear that, if the efforts of the War Department and the Navy Department were to be left totally uncoordinated, the war would be much more difficult, if not impossible, to win.

The Organization and Revisions to the Department of Defense, 1947-1958

The success of the national coordination boards pointed out the need for a civilian/defense superagency. This superagency would have to have executive powers to manage future mobilization and to coordinate procurement among the several armed services. In consideration of these requirements, the emergence of the Army Air Corps as a *de facto* separate service, the role of the Marine Corps in national defense,

and other issues, Congress drafted new legislation establishing an executive coordination authority over the services (Halperin, Clapp, and Kanter, 1974). This legislation, the National Security Act of 1947, established three separate departments: the Department of the Navy (including the Marine Corps), the Department of the Air Force, and the Department of the Army. The secretaries of these three departments were designated members of the President's cabinet. Each department was a single entity and the combined organization was the National Military Establishment. The head of this organization, the Secretary of Defense (SECDEF), was designated the principal assistant to the President in all matters pertaining to national security (Brady and Bancroft, 1973).

Since 1947 there has been a trend, within both the uniformed and civilian sides of the Defense organization, towards greater centraliztion. In 1949 a set of National Security Act Amendments were enacted that downgraded the Departments of Navy, Army, and Air Force and removed the service secretaries from the presidential cabinet. However, the authority of the Secretary of Defense was increased by making him the spokesman for the military departments in the National Security Council. In 1953 President Dwight D. Eisenhower, an advocate of centralization and unification, appointed Nelson A. Rockefeller the head of a committee to study the organization of the Office of the Secretary of Defense (OSD) and to make recommendations. As

a result of this committee's recommendations, the independence of the services was further limited by making the chairman of the Joint Chiefs of Staff responsible for managing the Joint Staff, by eliminating coordination boards with equal service representation, and by tripling the number of assistant secretaries from three to ten. This last action had significant impact on the services' approach to military systems acquisition because one of the new assistant secretaries was to have general responsibility for research and development (Bauer and Yoshpe, 1971).

From 1953 to 1958 concern for the need of even further revisions grew with the accelerating pace of technological developments; this rapid increase in technology was contributing to interservice rivalries from the competition for scarce Defense dollars. By late 1957 the increasing cost of weapons systems and the reactions of the American public to the technological successes of the Russians, particularly in space, brought significant pressure to bear for further revisions in management and control. In early 1958 a joint White House/Pentagon study was carried out that resulted in a reorganization of the Department of Defense (DOD) and its operations. These revisions centered on three areas: (1) An increase in the authority of the Secretary of Defense in planning DOD requirements, administrating the Department, and conducting military operations; (2) a provision for

a greater military unification for planning; and (3) a provision for unifying military commands for national objectives and policies.

The first revision, dealing with the increased power of the Secretary of Defense, most concerns us here. As a result of the new legislation in 1958, the several military departments were no longer to be separately administered, simply separately organized; they were clearly to be under the direction, authority, and control of the Secretary of Defense. The Secretary could propose to reassign, consolidate, transfer, or abolish both tactical and strategic functions and, therefore, effectively control the service missions and roles; these modifications could be limited only by Congressional authority. The Secretary's position was strengthened in the area of research and engineering by the establishment of the position of the Director of Defense Research and Engineering. This director was to be the Secretary's principal advisor on scientific and technical matters; he was to control and assign all research and development activities for the Secretary. This gave the Secretary the option to assign the development production and operational control of a system to whichever service he might decide, regardless of which realized the need for the system. This option clearly provided the authority for and pointed the way toward a centralized approach for

weapons-systems acquisition within the Department of Defense (Bauer and Yoshpe, 1971).

The McNamara Years

The implementation of legislation in 1958 completed a series of major revisions, beginning with the National Security Act of 1947, of the structure and the management practices of the Department of Defense. Although the 1958 Department of Defense Reorganization Act placed the Secretary of Defense in a position to take firm management control over the whole structure, no secretary chose to do so until Robert S. McNamara came into office with the Democratic administration in 1961. McNamara was strongly committed to exercising his full statutory authority in managing the Defense Department and had the strong support of the President in pursuing this goal. As his Assistant Secretary of Defense-Comptroller, McNamara chose Dr. Charles J. Hitch, previously a Rand Corporation economist. Hitch brought with him and implemented in the DOD the Planning, Programming, and Budgeting System (PPBS), which he had previously developed at Rand. This system was to bridge the gap between military planning and military budgets and required that planned military and naval forces be translated into specifically scheduled, time-phased actions that could be equated to well-defined resource requirements and budget-line items (Fabian, 1977).

The PPBS was introduced into the Department of Defense partially in response to systems-acquisition-related problems. A study by Peck and Scherer (1962) identified six specific problems related to the management of research, development, and production programs carried out by industry for the Department of Defense: (1) the schedule slippage, (2) an increase in cost, (3) a lack of qualified government personnel, (4) the high frequency of personnel turnover, (5) the inadequate methods of cost estimation, and (6) the insufficient training in the measurement and control of contractor performance. McNamara introduced the PPBS and a large Systems Analysis Group into the Office of the Secretary of Defense in an attempt to correct these problems and to more effectively control the resource-allocation process within the Department. The Systems Analysis Group was headed by Alain Enthoven, Assistant Secretary of Defense for Systems Analysis, whose role became one of the most powerful in DOD. Centralized management at the department level became a reality (Helmer, 1977).

Secretary McNamara demonstrated a deep and continuing concern for weapons-systems acquisition during his tenure in office. In a speech to the American Society of Newspaper Editors in April, 1963, he stated that

> ...we can develop only a fraction of the systems that are proposed. This process of choice must begin with solid indications that a proposed system would really add something to our national security. The United States cannot even seriously consider going ahead with a full-scale weapons-system development until that basic requirement has been met. [McNamara, 1976]

The B-70 bomber development program was cancelled because in McNamara's opinion, it failed to meet the criterion of a "substantial addition to national security." McNamara also reorganized the operational support establishments of the three military departments. The Army Material Command (AMC), the Naval Material Command (NMC), and the Air Force Systems Command (AFSC) evolved from this reorganization. Each command was to provide the weapons-systems-acquisition function for its respective service to increase the efficiency of the procurement and the support of new weapons systems as well as to keep pace with the rapidly changing technology base (McNamara, 1976).

McNamara further contributed to the DOD's systems-acquisition process by creating the Development Concept Paper (DCP, now referred to as the Decision Coordination Paper) to document the systems-acquisition program. The DCP approach was first formalized in a Secretary of Defense's memorandum in September, 1967 (Defense, 1967). This paper was to be the basic reference document for the system, documenting requirements, plans, projected costs, and accomplishments. Over time the DCP has evolved to the point where it now defines the development program and includes program objectives and plans, acquisition strategy, areas of significant risk, performance parameters, development alternatives, and operational requirements.

The determination of operational requirements for the military services is a specific example of how the Office of the Secretary of Defense practiced centralized management and exercised strong control over the Department. Assistant Secretary of Defense for Systems Analysis, Alain Enthover, and his staff played a pre-eminent role in determining operational requirements and in defining the overall problems of major weapons-systems-acquisition programs during the McNamara years. This limited and, in some cases, pre-empted the definition by the separate services of their own operational requirements (Enthoven and Smith, 1971).

The defining of requirements at the OSD level is an example of the centralized decision making during the McNamara years. The services were not allowed to participate in the decision process to the extent they would have desired. The Secretary or his immediate staff made most key decisions and the services were to a great extent overmanaged (Raymond, 1968).

Laird/Packard and New Approaches to Systems Acquisition

In 1969 the new Republican administration came into office with Melvin Laird as Secretary of Defense. David Packard was appointed as Laird's deputy (DEPSECDEF); an association began that was to have a great impact on DOD's management approach. Laird felt Packard's previous experience with a major Defense contractor was a positive quality and

enlisted Packard's support in what became known as "participatory management" in the Pentagon (Roherty, 1977).

Both Laird and Packard were alarmed by what they found in the systems-acquisition area of the DOD. They were concerned with the apparent overcentralization of the decision-making power of the OSD and with the status of various Defense acquisition programs. During 1969, the General Accounting Office (GAO) conducted a survey of thirty-eight major weapons-systems programs and found that projected costs to completion were 50 percent higher than the original cost figures on the contract. Two aircraft-acquisition programs, the C-5A and the F-111 programs, received a good deal of unfavorable public attention. The operational requirements for the C-5A program, which limited design trade-offs and led to significant cost overruns, were so numerous that the program failed. The F-111 fighter program had technical problems and an unpredicted cost growth--from an estimated $2.8 million per unit in 1962 to an estimated $14.7 million per unit in 1970. The problem varied from ineffective program management on the government's part to poor DOD/contractor relationships and overspecified operational requirements (Helmer, 1977).

A major reorganization of the systems-acquisition process was needed. Mr. Packard, the official responsible for all DOD research, development, and production, assumed this task. In 1970, he candidly expressed his concern in a

speech when he stated, "Frankly, gentlemen, in Defense [DOD] procurement, we have a real mess on our hands, and the question you and I have to face up to is what are we going to do to clean it up" (Helmer, 1977). Prior to this speech, he had already partially answered this rhetorical question by issuing two memoranda, one in May, 1969, and one in May, 1970, respectively entitled *Establishment of a Defense Systems Acquisition Review Council* and *Policy Guidance on Major Weapons Systems Acquisition* (Defense, 1969a, 1970b).

In the May, 1969, memorandum, Packard established the Defense Systems Acquisition Review Council (DSARC), which was intended to complement the Decision Coordinating Paper (DCP, previously referred to as the Development Concept Paper) to form a complete management system for major Defense systems acquisitions. This memorandum spelled out the mission, functions, composition, authority, and responsibilities of the DSARC. The mission of the DSARC was set forth as follows: "to review major and important Department of Defense systems-acquisition programs at appropriate milestone points in their life cycle." Three major milestones were identified as the review points:

I. The initiation of a contract definition,

II. the transition to full-scale development, and

III. the approval of a system for production.

Top-level DOD managers were to sit on this board to review and evaluate the program and to deliberate among themselves

on recommended program actions presented by the several services. Based on this process, the DSARC was to report on the current status of the program and to make recommendations to the SECDEF for the final decision on whether to continue the program (Defense, 1969a).

The memorandum of May, 1970, was written after Packard and his staff had studied the systems-acquisition problem for over a year. It set forth new policy guidelines for systems-acquisition management and for Defense contracts and defined the phases of the acquisition process as follows: conceptual development, full-scale development, and production. One principal policy thrust of the memorandum was to obtain and retain qualified personnel in the systems-acquisition process. The need to assign program managers for extended periods to build up expertise was also pointed out. The development policy dealt with milestones, risks, trade-offs between operational requirements and engineering design, and questions of schedule. Contract policy directed that the contract be tailored to the nature of the program risks. In the memorandum, Packard clearly stated his desire for a strong service participation in the acquisition of Defense systems. He pointed out the need for OSD to establish acquisition policies and to evaluate the performance of the services which were to develop and procure the major weapons systems. (Defense, 1970b).

During this same time, the DOD's management practices were undergoing a formal analysis by the Blue Ribbon Defense Panel. This panel's staff director, J. Fred Buzhart, was later the General Counsel of the DOD. Under his direction the panel developed a final report (Defense, 1970a) that outlined a set of recommendations relating to procurement and contracting procedures. This report was given to the President and the SECDEF on July 1, 1970. Both Laird and Packard found some of the panel's recommendations restrictive but the report did affect the overall revision of the systems-acquisition process.

Packard's two memoranda and certain recommendations from the Blue Ribbon Defense Panel formed the basis for a new systems-acquisition directive; DOD Directive 5000.1 was issued on July 13, 1971 (Defense, 1977a). This directive restated the policies previously established and went further in delineating OSD and service responsibilities. The directive established several criteria for deciding whether a system could be considered a major program: (1) If estimated research, development, test, and evaluation (RDT&E) costs were over $50 million or production costs were over $200 million; (2) if there were a national emergency, and (3) if there were a recommendation from DOD component heads or OSD officials. The order covered program responsibilities; the conduct of a program, including milestones/DCP development; and the DSARC requirements. It also covered the definition of requirements, cost

parameters, logistical support, uncertainties, test and evaluation, contacts, and source selection. The order was to apply to all military departments and to other DOD agencies, such as, the Defense Communications Agency.

Another innovation of Packard's was to introduce the concept of *prototyping* into Defense systems acquisition. Although this *fly-before-buy* approach was not new (it had been used for aircraft development prior to World War II), this was the first time it had been established as a formal policy within the Department of Defense. In its most desirable form, prototyping meant that competing contractors produced a limited number of preproduction or prototype end-items for test and evaluation prior to the award of the production contract (Roherty, 1977). This approach could not be applied to all acquisition programs; but the F-16 program, where General Dynamics and Northrop competed during development, is an excellent example of the implementation of prototyping. Packard (1973) outlined the benefits of prototyping to include improvements in total-program-cost estimates, in the means by which the operation of a system could be evaluated before production, in the verification of new technology, and in the enhancement of a systems reliability. Massey (1973) picked up on Packard's theme and suggested that already operational systems could be improved by using an experimental prototyping approach to operational RDT&E.

Packard was also deeply concerned that the services, particularly the program managers, should manage their own programs. He felt that the services had the primary responsibility for acquiring new systems. He stated, "My study convinces me that during the past few years, as programs got into trouble, OSD offices became too deeply involved in second guessing the services and in making overriding decisions" (Packard, 1971). He insured that the services did their own concept definition for new systems; the DCP's were to originate with the service having the requirement and not with the Office of the Director of Defense for Research and Engineering (DDR&E).

Packard's interest in service prerogatives is reflected in the DSARC's record for 1970. During that year twenty-one DSARCs were held: eleven times the DSARC approved a service-recommended action; six times it granted limited approval; three times it requested the service go back and do further work; and one time it deferred a decision pending Congressional support (Packard, 1971).

Barry J. Shillito (1971), then Assistant Secretary of Defense, stressed the following revisions to systems-acquisition management during DEPSECDEF Packard's tenure in office: the establishment of the DSARC, the development of decentralized guidelines, the clarification of OSD responsibilities, the establishment of milestones, the adoption of a *fly-before-you-buy* concept, the formal publication of

new acquisition policies, and the encouragement of new contracting procedures. Additionally, service involvement in the acquisition process was emphasized, with particular concern for the prerogatives of the program managers. These new policies and procedures for systems acquisition contrasted markedly with the approach during the McNamara years; they set the framework and tone for systems acquisition in the 1970's.

The Impact of the Office of Management and Budget's Policies

During the late 1960's and early 1970's, Congress was also concerned about federal procurement policies. As a result in November, 1969, Congressional legislation was passed that created the Commission on Government Procurement. This commission was to study federal procurement policies and procedures and to make recommendations to Congress concerning the promotion of practical, cost-effective and -efficient means of procurement by the federal government's Executive Branch. The work of this commission resulted in the Report of the Commission on Government Procurement, which was given to Congress and the Executive Branch in December, 1972. This report contained recommendations for establishing the need and objectives of new programs related to the basic missions of the government agencies. It also suggested that alternative development approaches and the means

to select preferred alternatives be explored and system-implementation questions be answered.

The commission's recommendations had a significant impact on the federal government's perception of how to carry out procurement. The executive branch's consideration of the commission's recommendations resulted in the Office of Management and Budget's (OMB) issuing OMB Circular No. A-109 on April 5, 1976, entitled *Major Systems Acquisitions*. This circular established policies to be followed by executive-branch agencies when acquiring major systems and, therefore, applied to the acquisition of weapons systems by the DOD.

OMB Circular No. A-109 pointed out that the management of the acquisition of major systems should include analyzing agency missions; determining mission needs; setting program objectives; determining system requirements; planning, budgeting, and funding the program; RDT&E; contracting; producing the system; establishing program and management controls; and introducing the system into use. It also outlined a set of definitions for terms, including *agency mission, mission need, program objectives, program, major system, life-cycle cost,* and *systems-acquisition process* (Appendix A).

The circular also established the following general policies for federal agencies acquiring major systems:

1. Express needs and program objectives in mission terms, not equipment terms.

2. Emphasize the early and continuous activities in the systems-acquisition process that will stimulate a competitive exploration of alternative systems-design concepts in response to mission needs.

3. Convey to Congress the plans for each major systems acquisition relating the system to agency mission needs.

4. Establish clear lines of authority and responsibility for systems acquisition and obtain agency-head approval at key decision points in the acquisition process.

5. Designate an acquisition executive for each agency to integrate and unify the management process for the agency's major systems acquisitions.

6. Establish a program-management office for each major systems acquisition.

7. Rely on private industry for support of the systems-acquisition process in accordance with the policies outlined in OMB Circular No. A-76 (OMB, 1977), which required the minimization of in-house government work that could be accomplished in the private sector.

Major systems-acquisition management objectives were also set forth in the circular and are briefly summarized below:

1. To insure that each major system fulfills a mission need;

2. to provide for competition among various systems-design concepts throughout the entire acquisition process;

3. to insure that there are appropriate trade-offs among investment costs, ownership costs, schedules, and performance characteristics;

4. to establish a strong set of checks and balances by adequate test and evaluation of the system;

5. to plan the acquisition of a system based on an analysis of the agency mission, including an appropriate resource-allocation process resulting from a clear statement of agency-mission needs;

6. to tailor an acquisition strategy to each program, refining the strategy as the program proceeds through the acquisition process.

The circular also stated that technical and program decisions should normally be made at the level of the agency or operating activity. However, the circular specified that the following four key decisions should be made by the agency head:

1. The identification and definition of the specific mission need to be fulfilled, the relative priority assigned within the agency, and the general magnitude of resources that could be invested;

2. the selection of competitive systems-design concepts to be tested or demonstrated or the authorization

to proceed with the development of a noncompetitive (single-concept) system;

3. the commitment for the full-scale development and limited production of a system;

4. the commitment for the full production of a system.

The requirements of the agencies to prepare for the initial milestone through mission-need analysis became a key element of the policies set forth in the circular. Mission needs had to be determined from an analysis of the agency's mission reconciled with the overall capabilities, priorities, and resources. The circular further stated that a need should not be defined in equipment terms but should be defined in terms of the mission, the purpose, the capability, the agency components involved, the schedule and cost objectives, and the operating constraints. A mission need was to be established independently of any particular system or technological solution and was to be identified, well defined, and documented prior to the initial decision point of the system-acquisition process.

The overall framework for the systems-acquisition process as established by the policies of A-109 (OMB, 1976) is graphically portrayed in Figure 1. An analysis of mission needs is on the left of the chart, with consideration for overall capabilities, priorities, and resources. The process moves to the right as a function of time and passes through the four major decision milestones for the validation of a

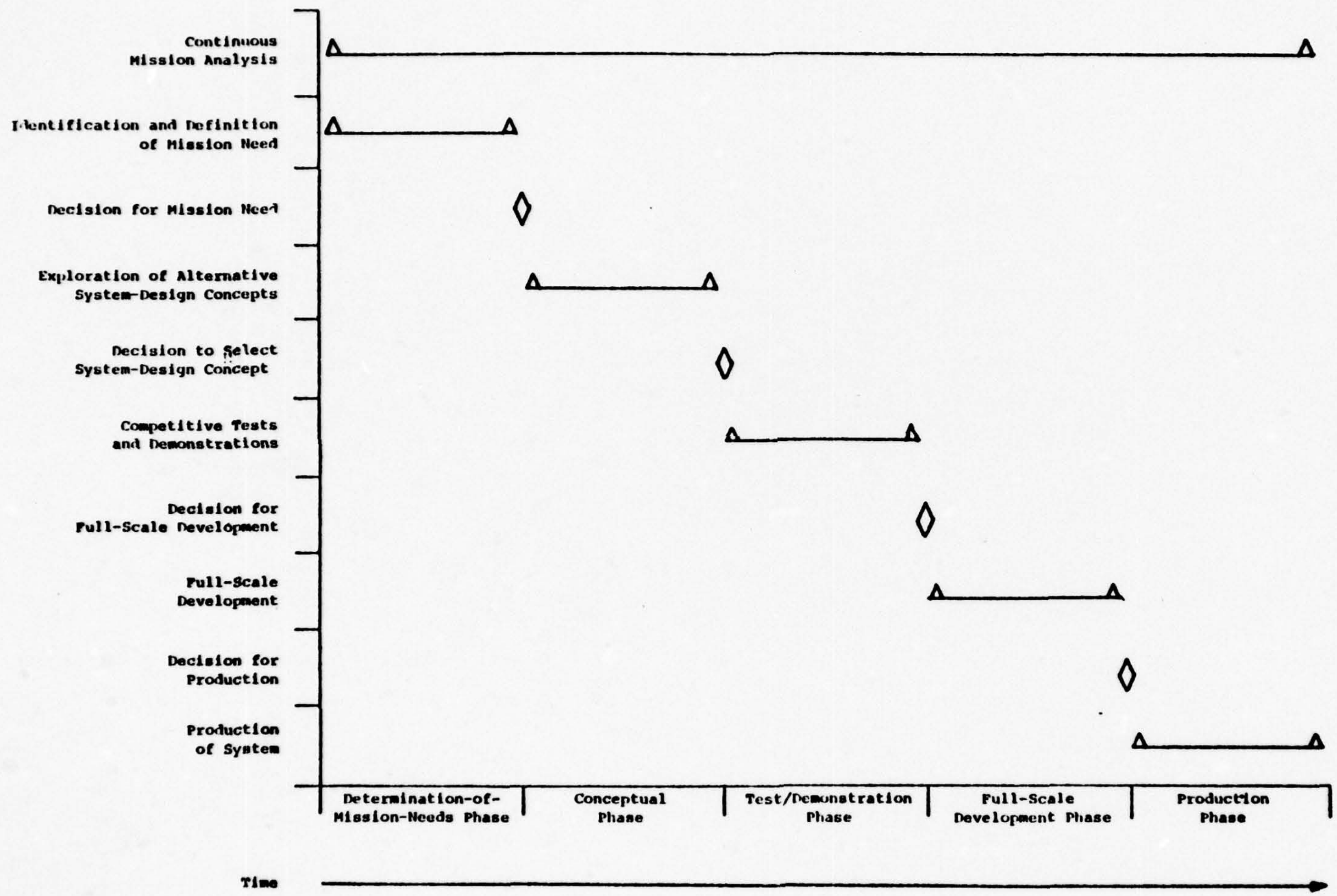


Figure 1. Sequence of Activities and Decisions to Implement the Policies of OMB A-109 (1976).

mission need, the selection of concepts for demonstration, the selection of the alternatives for full-scale development, and the production decision. Each decision is subject to agency-head approval.

OMB Circular A-109 (1976) was reasonably well received within the federal establishment and the private sector. Musgrave (1976), writing from the perspective of a naval officer involved in DOD systems acquisition, provided a favorable review of the policies of A-109 and the initial implementation steps. Some benefits he attributed to the A-109 approach were the improved linkage between resource inputs and service-program needs; a high incidence of aggressive and innovative problem solving, the integration of technical disciplines into productive system-oriented teams, and the avoidance of suboptimal designs by looking at the total problem, not a component of it.

The importance of A-109 in planning for major Defense systems and its impact on federal procurement was outlined by Coleman (1978). He pointed out that the Navy was criticized by GAO for requesting information from industry on vertical take-off-and-landing aircraft subsystems--engine, airframe, and avionics--instead of for the system as a whole, as A-109 required. Harlamor (1978) indicated general aerospace-industry support for A-109 but felt careful implementation would be required for the directive to be successful. He also noted the unqualified

support of the aerospace industry for the portion of A-109 that referred to OMB Circular A-76 (1977) and its requirement to use industrial sources in preference to government in-house capabilities to carry out development efforts.

An Overview of the Current Process

Since A-109 was issued in April, 1976, the Department of Defense has taken significant steps to implement the policies in the circular. A revised version of DOD Directive 5000.1, *Major Systems Acquisition,* was issued on January 18, 1977. This was an update of the previous directive of that number, which could be traced back to the original directive of July, 1971, and DEPSECDEF Packard's 1969 memorandum. A complementary order, DOD Directive 5000.2, *Major Systems Acquisition Process*, was also published on January 18, 1977. These two directives, along with DOD Directive 5000.3, *Test and Evaluation* of April, 1978, effectively established the acquisition policies of A-109 for the DOD (Defense, 1977a, 1977b, 1978).

The provisions of the new DOD Directive 5000.1 defined major systems as those that were so designated by the SECDEF, those that were recommended by DOD component heads and OSD officials, and those with an anticipated cost of $75 million for RDT&E or $300 million to produce. The following four key SECDEF decisions were to be made at distinct phases of the program:

1. Milestone 0 - the decision to initiate a program;

2. Milestone I - the decision to proceed to demonstration and validation;

3. Milestone II - the decision to proceed to full-scale engineering development;

4. Milestone III - the decision to produce and deploy.

The overall acquisition policies set forth in 5000.1 (Defense, 1977a) were consistent with those already mentioned for A-109 (OMB, 1976). In fact the new 5000.1 was generally consistent with previous versions of the directive with one major exception. Although the definition of a problem and the identification of requirements had been major considerations for years with systems-acquisition programs, this was the first time that a SECDEF decision was mandatory to approve the requirements and intitate the program.

The 5000.1 directive stated that before a Milestone 0 decision point could be reached, the SECDEF must have requested a new capability, or a DOD component (one of the services) head must have realized a mission need and determined that a new capability was necessary to meet that need. Once this point was reached, the DOD component head must submit a statement of the mission need to the SECDEF and request approval to identify and explore alternative solutions. The directive also stated that support for determining the mission need must have been documented in the Mission Element

Need Statement (MENS). Once a mission need was determined to be essential and reconciled with other DOD capabilities, resources, and priorities, the SECDEF would approve the mission need. After this decision, one or more of the DOD components must systematically and progressively explore and develop alternative systems concept.

The DOD Directive 5000.2 (Defense, 1977b) amplified the general policies of 5000.1 (Defense, 1977a) and provided definitive guidelines for advisory councils, program reviews, mission-area analyses, program-management considerations, and program documentation. Two advisory councils were established by the 5000.2 directive to review major-systems programs at Milestones I, II, and III and to make recommendations to the SECDEF. The DSARC, the senior council established by the order, had been used by DOD since DEPSECDEF Packard's 1969 memorandum (Defense, 1969a); the DSARC charter outlined its membership, its participants and advisors, and its operations. The procedures to be used by the DSARC were generally consistent with those of previous years. A Defense Acquisition Executive (responsibilities outlined in DOD Directive 5000.30 [Defense, 1976]) was designated as the Chairman of the DSARC. A graphical representation of the number of DSARCs held since DEPSECDEF Packard initially directed this management approach is provided in Figure 2.

The second advisory council established by 5000.2 was the (Service) System Acquisition Review Council ([S]SARC).

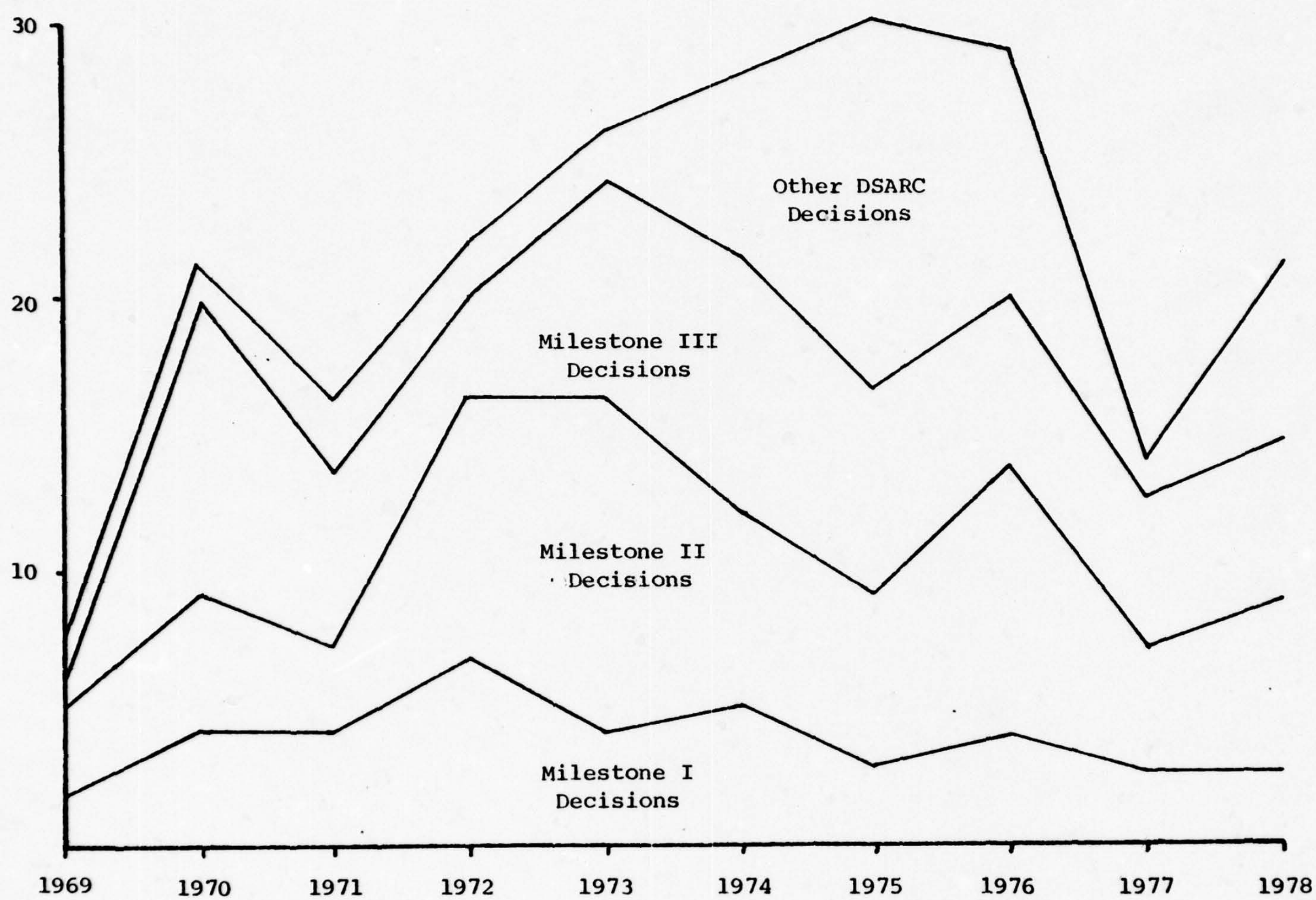


Figure 2. DSARC History (SOURCE: Defense, 1979).

This directive required that each Service Secretary charter a (S)SARC similar in composition, responsibilities, and operation to the DSARC. The (S)SARC was to review major systems-acquisition programs and to provide advice to the Service Secretary either supporting a subsequent DSARC or, for selected programs, making recommendations to the SECDEF. Either the Service Secretary or the Under Secretary must chair the (S)SARC. DSARCs and (S)SARCs must be conducted at each milestone decision point for all major systems-acquisition programs except when specifically waived by the SECDEF.

The 5000.2 directive provided the authority for the SECDEF, with the assistance of the DOD components, to establish mission areas that reflected several operating categories essential to the accomplishment of a Defense mission. The DOD component heads were directed to carry out a continuing analysis of their assigned mission responsibilities in the several mission areas in order to identify those mission elements for which the existing or projected capability was deficient and to identify opportunities for enhancing the existing capabilities.

The 5000.2 directive also covered program-management considerations relating to the program manager's responsibilities and his position in the overall DOD management structure, the developmental status of subsystems projected for use in the overall system, and the importance of the MENS and its relationship to the Five-Year Defense Plan (FYDP),

Program Objectives Memorandum (POM), and the PPBS. The policies related to management in 5000.2 also included acquisition strategies, costs of acquisition and ownership, competitive demonstrations, contract considerations, and management information systems.

Two key documents, the MENS and the DCP, were required by 5000.2 to support the DSARC and (S)SARC reviews and to aid the SECDEF in making the best decision. The Mission Element Need Statement required that the service with the need:

1. Identify the mission area and state the need in terms of the task to be performed;
2. assess the projected enemy threat;
3. identify the existing DOD capability;
4. assess the deficiency in the existing capability;
5. state the known constraints applicable to any acceptable solution;
6. assess the impact of not acquiring the capability;
7. provide a program plan to identify and explore competitive alternate systems.

The Decision Coordinating Paper (DCP) required that MENS be completed, updated, and incorporated into the DCP and the following be provided:

1. The alternative programs;
2. the acquisition strategy;
3. the short- and long-term business planning;

4. the program structure and management plan;

5. the program uncertainties;

6. a technology-assessment annex, including areas of technological risk remaining in the program;

7. a resource-input annex, including cost, production, and inventory data;

8. a logistics-support annex;

9. the program schedule, cost, and performance information for Milestones II and III;

10. the test and evaluation planning and status;

11. the DSARC and (S)SARC results and recommendations;

12. the SECDEF decisions.

The 5000.2 directive outlined the requirements for processing and coordinating the DCP. The directive identified three separate sets of program issues that must be considered by the DSARCs and (S)SARCs at each milestone. Past DSARC and (S)SARC actions in relationship to the DCP were also covered in 5000.2.

An overview of the systems-acquisition process from the OSD-decision viewpoint is graphically depicted in Figure 3 The process begins at the top of the DELTA chart, with a continuing mission analysis and the existing technical base. A needed capability is then identified and translated into a MENS. Once the MENS is approved, phases of the acquisition program alternate with DSARC/DCP decision points. The decision points always proceed a major phase of the acquisition

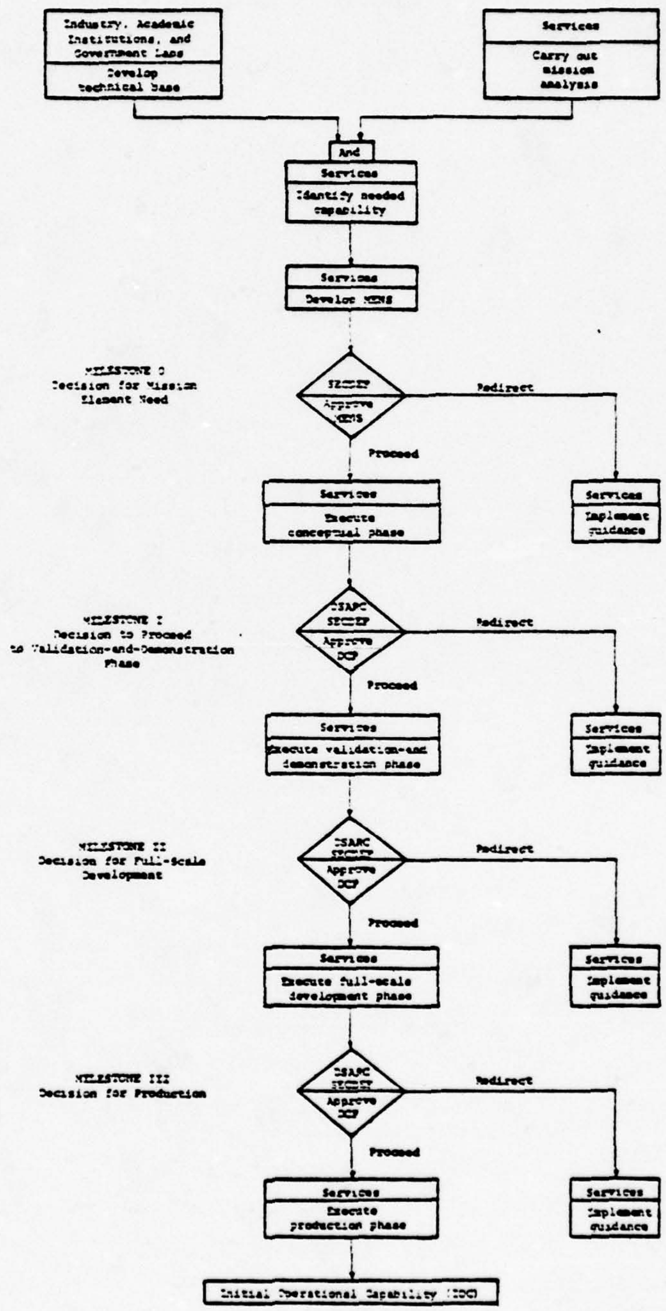


Figure 3. Activities and Decisions Required to Implement DOD Directives 5000.1 and 5000.2 (1977a,b).

program. These decision points provide a major review of the program status before approval is given to proceed to the next milestone. The final major-decision point is Milestone III, the production/deployment decision, which leads to a new operational capability.

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Chapter 2

THE RESEARCH PROBLEM: ITS NATURE, PURPOSE, AND SCOPE

Introduction

Major revisions of the weapons-systems acquisitions took place within the Department of Defense (DOD) in the early 1970's. The Deputy Secretary of Defense (DEPSECDEF) David Packard and others on the Office of the Secretary of Defense (OSD) staff instituted a new set of acquisition policies that included the establishment of the Defense Systems Acquisition Review Council (DSARC), the introduction of a *fly-before-you-buy* concept, the promotion of prototyping or dual development, and the formal publishing of the systems-acquisition milestones for management procedures. These innovations were quickly followed by the promulgation of Circular A-109 by the Office of Management and Budget (OMB) in 1976. This circular established new systems-acquisition policies for all executive agencies and had particular impact on the DOD's approach to the requirements-analysis portion of the systems-acquisition process. The circular also directed that the mission-area analysis continue and required that a Mission Element Need Statement (MENS) be developed for each major program. Two revised DOD directives, 5000.1 (*Major Systems Acquisitions*) and 5000.2 (*Major Systems-Acquisition Process*) were issued in 1977 to implement the new policies in OMB Circular A-109 (Defense, 1977a, b; OMB, 1976).

Circular A-109 and the two DOD directives established a strong, comprehensive, and well-conceived policy framework within which to manage DOD systems acquisitions. In light of this policy framework, the process of acquiring Defense systems should have proceeded smoothly, with a minimum of problems. However, this was not the case; wide-ranging problems have been identified in the systems-acquisition process during the 1970's. Some problems of the 1970's were holdovers from a previous time, such as, the Main Battle Tank-70 (MBT-70) Program (Croskery and Horton, 1974). Other problems, such as, our growing dependence on the foreign production of critical components and the minimizing of Defense procurement since the Vietman War (Gansler, 1977), are beyond the scope of the systems-acquisition-policy framework discussed above. But many problems that arose within Defense research and development (R&D) and the systems-acquisition process do fall within the scope of the policy framework: system testing and evaluation (Harrison, 1976); requirements analysis (Jordan, 1974); software development and standardization (DeRoze, 1975); and system reliability, maintainability, and availability (Gansler, 1976).

Many R&D-related problems within the DOD were caused by the size and complexity of the procurement programs for such diverse systems as cruise missiles (Canfield and Kellett, 1978); guided-missile frigates (Beecher and DiTrapani, 1978); command, communications, and control systems (Berry,

1978); and vertical-and-short-take-off-and-landing (VSTOL) aircraft (Coleman, 1978). The diversity of these acquisition programs, coupled with the variety of development problems similar to those mentioned above, have continued to challenge the DOD management structure. Therefore, the planning, control, and management of the systems-acquisition process is still a major concern within the DOD.

One cannot speak of the optimization (in the mathematical sense) of the systems-acquisition process because of the breadness and complexity of the problem. However, the improvement of the systems-acquisition process, particularly relative to the four major-decision milestones (0, I, II, and III), is certainly a meaningful goal--a goal which has been pursued in this dissertation by using systems engineering while considering the DOD policy framework. The research problem associated with this goal is discussed here; the purpose and objectives of the research are also presented. Comments are made on the scope and focus of this study and on the related literature; the overall organization of the report is also outlined.

The Problem Statement and Its Nature

Keeping in mind the description of the systems-acquisition process in the first chapter and the comments made in the above introduction, the overall research problem

is *to determine how the Department of Defense systems-acquisition process may be improved using systems engineering.* The emphasis of this study will be directed toward the four major-decision milestones (0, I, II, and III), the operation of the Defense Systems Acquisition Review Council and the (Service) Systems Acquisition Review Council ([S]SARC) advisory boards, and the use of the Decision Coordination Paper (DCP) and Mission Element Need Statement within the overall DOD-policy framework.

The idea of applying systemic methods to management and resource-allocation problems related to Defense is not new. Since World War II, quantitative techniques have been applied as a viable means of addressing the problems inherent to military operations (Morse and Kimball, 1951). Quantitative methods have been applied to research and development programs for fifteen years or more. Dean (1963), Roberts (1964), and Villers (1964) wrote about applying operations research or scientific means to the planning, management, and control of research and development programs.

Models from the current management-science/operations-research (MS/OR) could be used to construct a potentially useful, generalized description of the overall (macrolevel) systems-acquisition process. Clearly, significant insight could be gained into the nature and structure of the overall problem by using such models. For example, deterministic and stochastic dynamic processes and related optimization

models could be used to describe the sequential aspect of the acquisition problem associated with the four major-decision milestones, decision analysis could incorporate the notion of risk and uncertainties inherent in R&D problems, and game-and-team theory could provide for the trade-off of systems-acquisition programs competing for scarce resources.

The development of such a model for realistic prescriptive purposes would certainly involve substantial and possibly unresolvable difficulties. The multi-dimensional nature of DOD systems-acquisition problems and the fact that related functional relationships would often be, at best, difficult to establish suggests that precise formulation of the objectives function(s) and the concomitant constraints would be extremely difficult. Furthermore, the objectives and constraint functions that could be explicitly stated would likely inherit severe non-linearities and discontinuities. These technical considerations and the obviously large size of the model imply that the model would be intractable.

The discussion above is not intended to discredit MS/OR optimization techniques in their general application, but rather, to indicate that optimization techniques would be inappropriately applied at the macrolevel of the DOD systems-acquisition process if actual solutions are being sought. These techniques and others from the MS/OR area do have application to the resolution of systems-acquisition problems, but more appropriately at the level of the

activities (the microlevel) making up the several phases of the systems-acquisition process. At this level the problems could be more concisely stated, and the objective and constraint functions could be more readily formulated, thereby enabling credible solutions to be obtained from the optimization models.

At the macrolevel of the systems-acquisition process, an aggregate modelling approach is needed, which would be:

1. Broad enough to account for the multivariable nature of the process;

2. flexible enough to consider the inherent complexities of the problem;

3. time related to incorporate the several phases of the systems-acquisition process;

4. decision oriented to reflect the requirements of the several major-decision milestones;

5. adaptable enough to incorporate MS/OR techniques that could be used more appropriately at the microlevel (activities level) of the systems-acuqisition process.

A technical approach that embodies these characteristics, which are necessary for addressing DOD systems-acquisition problems, is systems engineering.[1] Robert A. Frosch (1969), formerly Assistant Secretary of the Navy for

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[1]Following Sage (1977), the word *systems* refers to the application of system science and methodologies associated with this science; the word *engineering* includes not only the mastery and manipulation of physical data but also implies social and behavioral considerations as inherent parts of the engineering-design process.

Research and Development, discussed the application of systems engineering to the systems-acquisition process. Specifically, he addressed the then current practice of systems engineering in relation to military systems development and pointed out several problems with that practice, including the entrancement with technique as a substitute for good judgment; employment of serial versus iterative development models; the fulfillment of schedule predictions as a criterion to evaluate development performance versus a set of evaluation factors associated with the fulfillment of a need; the failure to appropriately consider risk; and the optimization of the system to meet a very specifically defined operational requirement. Frosch also indicated the need to provide managers of Defense systems-acquisition programs "a good choice of managerial and systems-engineering tools" to carry out their responsibilities.

The work of David Packard and others, as related in the section *Laird/Packard and New Approaches to Systems Acquisitions* (p. 10), did much to improve the managerial tools for the Defense systems-acquisition process; particularly in his efforts to strengthen the program-management function and the establishment of the DSARC. However, it was the author's perception that Frosch's proposed set of "good systems-engineering tools" had not yet evolved to assist top-level DOD managers in their systems-acquisition decision process. Therefore, this research was directed toward the development of a systems-engineering methodology to support

the systems-acquisition decision process. In response to the problems noted by Frosch, several items were considered in developing the methodology: the use of techniques that complimented the judgment and experience of top-level decision makers, the employment of iterative models of the development cycle, the establishment of a broad set of criteria for program evaluation, the overt consideration of risk and uncertainty and its impact on the various phases of the development effort, and the pursuit of systems-acquisition improvement and not necessarily optimization.

The systems-engineering approach is used in this dissertation as the means for improving the Defense systems-acquisition process.

Purpose and Objectives of the Research

The application of systems engineering to the Defense systems-acquisition process is specifically addressed in this dissertation. This was done with the DOD-policy framework outlined in Chapter 1 and deals with large-scale systems-acquisition problems, including application.

The following research objectives were developed:

1. To suggest conceptual improvements in the Defense systems-acquisition process;
2. To present a validated systems-engineering methodology to improve the systems-acquisition process;

3.1 To develop a systems-engineering methodology for the Defense systems-acquisition process:

4.1.1 To examine the nature and structure of the systems-acquisition process;

4.1.2 To establish criteria for the application of systems-engineering procedures to Defense systems acquisition;

4.1.3 To gain insight into the structure of the value system and procedures associated with the systems-acquisition process;

4.1.4 To identify appropriate implementation procedures for the systems-engineering method within the DOD policy framework.

3.2 To demonstrate the applicability of the systems-engineering framework to an applied Defense systems-acquisition problem:

4.2.1 To analyze a development program that has benefited by the application of systems-engineering techniques;

4.2.2 To analyze a program that has suffered from the lack of a systems-engineering approach.

The objectives tree in Figure 4 shows how the objectives at each level will contribute to the accomplishment of the next

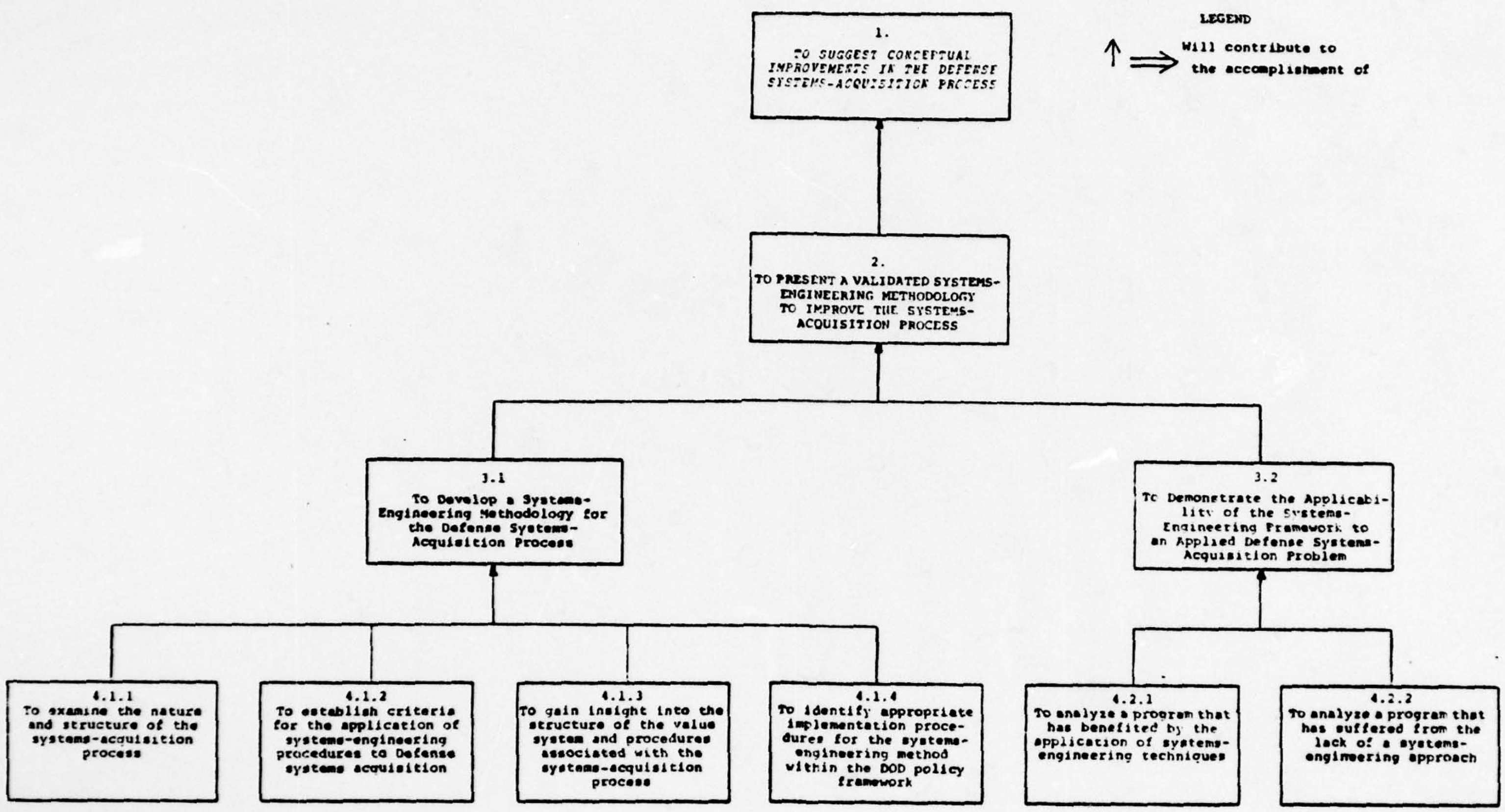

Figure 4. Objectives Tree for the Dissertation Research.

higher objective. The objectives become more specific and concrete as one moves down the tree.

The level-1 objective is a value-laden objective, suggesting the possibility of improving the Defense systems-acquisition process. The level-2 objective relates to the employment of a systems-engineering methodology to improve the process. Accomplishment of this objective is dependent on the level-3 objectives, dealing with the development of a systems-engineering methodology and the application of a systems-engineering methodology to an applied problem. The several tasks of this dissertation were directly related to the level-2 and -3 objectives.

Scope and Focus of the Study

This dissertation concentrates on the application of systems engineering to the DOD systems-acquisition process. However, it is important to note the following limitations:

1. *Policy Considerations.* The investigation was generally conducted within the policy framework established by OMB Circular A-109, DOD Directives 5000.1 and 5000.2, and the other applicable directives. The various decision points, the membership of decision groups, the specifically defined organizational relationships and procedures were usually accepted as established by these directives. However, it may be appropriate, based on the research, to identify systems-

acquisition-policy initiatives that could improve the overall process.

2. *Organizational Considerations.* The Department of Defense is the focal point of this study; the relationship of DOD to Congress and agencies of the executive branch, such as, the Office of Management and Budget (OMB), was considered only as they interfaced with the systems-acquisition process. The detailed inner workings of these organizations are not addressed. Also, organizations within the Department of Defense whose principal responsibilities were peripheral to the systems-acquisition process were not studied in depth. For example, the intelligence-related organizations within DOD were considered since they provided enemy-threat assessments for the requirements-definition problem. However, threat assessments were considered as given inputs to the systems-engineering effort, without concern for their specific development.

3. *Life Cycle of the Overall System.* This investigation covers the time from when the requirement for a new mission-element need is first identified until a final decision is made for the production and deployment of a system. The life cycle of those phases of the overall system dealing with production, distribution, operation, and retirement are not addressed.

4. *Depth of Analysis.* This study is primarily concerned with the nature and structure of the systems-

acquisition problem. Each phase of the development effort was evaluated to see what activities needed to be performed and how the activities could best be represented or analyzed. Considerations were developed for applying systems-engineering tools and techniques to the various steps of each phase. These considerations were then used to identify where in the systems-acquisition process the various tools and techniques of systems engineering could best be applied. However, detailed mathematical models were not formulated in response to specific systems-acquisition-analysis requirements.

5. *Program-Management Considerations.* The overall management of systems acquisition is considered on the DOD and the service-headquarters levels. Program management is addressed from the program manager's viewpoint, concentrating primarily on his relationships and responsibilities to the DSARC/(S)SARC.

Emphasis is placed on the major-decision milestones (discussed in Chapter 1) as beginning and end points of each phase of the systems-acquisition process--i.e., each milestone represents the end of the preparations and analysis steps leading to the decision and the beginning of the next phase of the systems-acquisition process. By making the decision milestones the focal point of the study effort, operations and responsibilities of the DSARC/(S)SARC are highlighted. These councils are one of the principal means by which DOD has implemented the systems-acquisition policy.

Therefore, this dissertation emphasizes the following aspects of the DSARC/(S)SARC: the personnel makeup of the decision groups, the value systems operating within the council, the council proceedings, the decision process of the members, and the impact of the decisions on the overall systems-acquisition process.

Comments on Related Literature

A great deal of material in the literature was related to the general area of research and development. This material was principally centered on three areas: (1) The selection and evaluation of research or development projects; (2) the use of management-engineering techniques in research and development; and (3) the management of development projects.

In the first area, wide-ranging methods for the evaluation and selection of projects were discussed in survey articles by Cetron, Martino, and Roepche (1967); Augood (1973); Baker (1974); Clarke (1974); and Baker and Freeland (1975). The Cetron, Martino, and Roepche article addressed the application of quantitative methods to the selection of R&D programs. It presented the characteristics of the methods, commented on their ease of use, and classified the methods by type; i.e., operations research, economic analysis, or decision theory. The Augood article documented a variety of R&D-evaluation methods and associated techniques.

Checklists, various R&D indices (i.e., risk analysis, decision analysis, and impact analysis), and combined methods were discussed.

In his article, Baker described the R&D project selection problem as consisting of the requirement to generate alternatives, to determine the need for a decision, to collect data, to specify constraints and criteria, and to recycle. He assessed the existing R&D benefit-measurement and project-selection literature and discussed the limitations of the various models. Clarke's (1974) paper discussed the factors to be considered when a manager has to decide whether a concept, product, or system is to go to the next stage of the development process. The literature reviewed covered the following topics: idea generation, transmission and evaluation, project selection and evaluation, and the impact of project-selection models on scientists and engineers. Several classes of mathematical models to be used for project selection and evaluation were also presented.

The Baker and Freeland (1975) paper assessed the literature addressing quantitative models for R&D project selection and resource-allocation decisions. The literature surveyed was dichotomized into benefit-measurement methods and resource-allocation methods. The paper discussed the strengths and limitations of existing methods and emphasized empirical investigations. A variety of methods was discussed, including

decision analysis, scoring models, zero-one approaches, and mathematical programming models.

Management engineering and its application to research and development has also received a good deal of attention in the literature. An excellent example is Warfield and Hill's (1971) paper dealing with the portrayal of R&D projects through DELTA charts. DELTA charts may be used to describe not only events and activities but also decision and logic function. The paper pointed out the critical need to portray these functions, which are so important in representing the alternate approaches and feedback loops that are integral to R&D project planning.

The Work Plan Analysis and Scheduling Technique (WoPAST) was developed by Delgrosso and Rosenbluth (1976) to plan and schedule complex engineering programs when early ideas and goals were still in a state of flux and responsibilities were general and not clearly defined. Their paper pointed out that the object of WoPAST as a tracking and scheduling device is to define activities, measure progress, and react to problems. WoPAST merged the procedures of the program evaluation and review technique/critical path method (PERT/CPM) with communications and feedback techniques appropriate to the organization of the user.

A management-engineering technique that has been applied to R&D was originally developed by Pritsker and Happ (1966), and Pritsker and Whitehouse (1966). Moore and Taylor

(1977) used this technique to address multiteam, multiproject research and development planning. Specifically, this paper reported on a simulation study of multiple research and development projects that were investigated concurrently and sequentially by more than one research team. GERT was suggested for use because of its capability to incorporate the probabilistic outcomes and feedback loops that are common to R&D projects.

The papers discussed above are not intended to be a comprehensive review of the management-engineering techniques that can be applied to research and development. Rather, these papers should be viewed as representative of the type of research taking place in this area.

The third major area of extensive work and publication related to R&D was project management. A variety of texts and manuals have discussed the area of project management in great depth.

Blanchard (1974, 1976, 1978) did an excellent job of setting forth the systems life-cycle problems. Among other topics, he covered planning, development, product research, design, test and evaluation, production, and life-cycle costs. His work was particularly significant in the context of this dissertation since much of it was related to Defense R&D.

In his text on the management of systems engineering, Chase (1974) discussed a wide-ranging set of topics, including

the system design, management organizations, operational considerations, testing and evaluation, software engineering, dealing with intangibles, and risk assessment. The Department of the Navy's Naval Ocean Systems Center, San Diego (1977), recently published a *Project Manager's Guide* for use by developers of naval systems. It addressed the chronology of systems development and the key disciplines involved. Since this document dealt almost exclusively with Defense development programs, it was highly relevant to the programs considered in this dissertation.

Shinners (1976) directed his text toward the systems engineers and program managers working on large, technologically complex programs. He noted the need for interdisciplinary teams and effective communications techniques. Shinners also discussed systems engineering and systems management from both the practical and analytical viewpoints. In his text, Archibald (1976) developed a generic perspective of project management generally applicable to many tasks. Although written primarily for project managers, this text also contained many useful insights for those who manage project managers and those who support project managers in functional and staff departments. The book is divided into two major parts: an executive guide to program management and the management of specific projects. Coutinho (1977) addressed the development management of advanced systems. He covered many topics; including procurement, contracting, design

assurance, organization for management, quality assurance, operational testing, and professional responsibilities. This text was also oriented towards Defense systems development. Hajek's (1977) book presented the various facets of project management, chronologically covering the life cycle of a system from the time a company took an interest in the project until the system was accepted and support was established. Throughout the book, the procurement of a land-mass simulator was used as the vehicle for illustrating the various principles and disciplines involving a project engineer.

Collectively, these several references dealt in detail with various aspects and functions of project management. However, the dissertation deals with this subject only in a general way and emphasizes the upper levels of the hierarchy of systems-acquisition management.

The three general areas of R&D technical literature discussed above were the selection and evaluation of research or development projects, management-engineering techniques, and development-project management. The work in the first area focused on the relatively narrow aspects of specific decision points associated with R&D projects. The second area of work addressed only certain project facets, which were a subset of the overall systems-acquisition process. Finally, the project-management texts tended to accept the problem

as reasonably well defined and generally did not touch upon policy considerations.

The need for an enlightened, comprehensive approach to the management problem of Defense systems acquisition must be considered. Two recent articles suggested the need for a broad systems approach to research and development. Paul Polishuk (1976) identified the need for an interdisciplinary approach to policy analysis and problem solving due to the increasing complexities of government policy and decision making. John W. Lathrop and Kan Chen (1976) wrote of the relevance of systems theory to the evaluation, comparison, and planning of R&D programs with diverse objectives, uncertain outcomes, and multidimensional benefits and costs. Both articles noted the need for a systems-engineering framework within which government research and development programs could be carried out. In like manner, Lawrence S. Hill (1970) presented a historical analysis of the early use of certain aspects of a systems-engineering approach to government R&D programs and commented on the benefits of such an approach.

The application of systems engineering to federal R&D and, specifically, to the Defense systems-acquisition process is the subject of the research associated with this dissertation.

Organization of the Report

The purpose of the research presented in this dissertation is to address the question of the application of systems engineering to military systems acquisition within the DOD-policy framework previously discussed. The actual research was divided into three major tasks. Each task is covered in a self-contained chapter, which includes the references appropriate to that chapter.

The DOD systems-acquisition material for the report was developed from three sources; DOD directives and other documentation, interviews with DOD personnel involved with systems acquisition (Appendix B), and the author's personal experiences in four years of Defense R&D. A questionnaire for those personnel interviewed is presented as Appendix C.

The first major task was to analyze the structure of the problems of Defense systems acquisition. A general systems-engineering framework was adopted to analyze the problems and the underlying structure of the Defense systems-acquisition process was examined. The systems-engineering framework and the systems-acquisition process were compared on a step-by-step basis to determine the correlation between the two procedures.

The second major task concerned the development of a systems-engineering methodology for application to the Defense systems-acquisition process. The nature and

structure of the systems-acquisition process were examined, considerations for the application of the systems-engineering tools and techniques to the systems-acquisition process were identified, and a systems-engineering methodology was developed to support the decision process. The implementation of this methodology by the Department of Defense is discussed.

The third major task was to analyze an on-going, real-world, military systems-acquisition problem using a systems-engineering approach. Initially, this program was examined when it suffered from the lack of a systems-engineering approach. The same program was then examined to see if and how it benefited by applying a systems-engineering method similar to that developed in the previous task.

The final chapter is devoted to the summary, conclusions, and recommendations for follow-on research.

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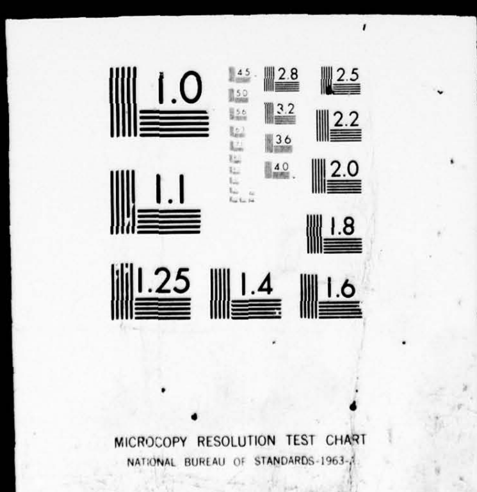

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Chapter 3

THE STRUCTURE OF SYSTEMS-ACQUISITION PROBLEMS OF THE DEPARTMENT OF DEFENSE

Introduction

The multidiscipline approach of systems engineering has been a reality for almost forty years. A. D. Hall (1962) indicated that the initial use of the term *systems engineering* might be attributed to the Bell Telephone Laboratories during the early 1940's when they used a systems approach to develop the Bell network. Lawrence S. Hill (1970) identified the Glenn L. Martin Company as an early practitioner of systems engineering, for the formation of their Special Weapons Group in 1945. Hill cited Martin Company literature on the Special Weapons Group that stated "the problems we face in progressing into the future consist, first of all, in devising ways and means for expanding the application of the systems-engineering concept."

The military-oriented work of Martin's Special Weapons Group and the work of the California Institute of Technology's Jet Propulsion Laboratory (JPL) for the U. S. Army Air Corps are early examples of systems-engineering work supporting Defense-related projects. During World War II the JPL supported efforts to apply the principles of rocket-motor design to aircraft (Pickering, 1973). Towards the end of the war, when Army Ordinance asked the JPL to explore the possible

use of rockets in long-range artillery, rocket motors, fuel tanks, guidance systems, and payload all had to be considered. Therefore, engineers from a variety of disciplines were forced to work together and a very crude systems-engineering approach slowly emerged.

Next, the JPL developed an operational missile system (Corporal) for Army Ordinance. Many different problems arose in developing Corporal that were solved by a team of engineers from several disciplines. These problems included defining operational requirements, identifying constraints, establishing goals, integrating systems, communicating with users and sponsors, and transferring the necessary technology to the industrial company producing Corporal. The solution of these problems led to the evolution of a meaningful systems-engineering organization at JPL, which further matured through the total systems responsibility JPL was given to develop the second-generation Sergeant missile during the 1950's. Development of this missile was a classical systems-engineering task for a large and complex system and was successfully completed just as the JPL was transferred to NASA in 1958 (Pickering, 1973).

The Apollo project carried out by NASA during the 1960's was a natural extension of the pioneering systems-engineering efforts carried out by JPL and others in the previous decade. This was the largest engineering enterprise ever undertaken, involving an expenditure of $20 billion and the efforts of

more than 200,000 people. George E. Mueller (1973), Associate Administrator for NASA's Manned Space Flight from 1963 to 1969 stated that "the [Apollo] program...suggests the necessity for creativity and innovation in modern systems engineering." This statement and Mueller's discussion of goal-setting procedures, the development of operational requirements, and the requirement for systems tradeoffs are strong recommendations for using viable systems-engineering techniques.

One of the pioneers of systems engineering during the 1950's and 1960's was Simon Ramo. He was the chief scientist for the Air Force on the intercontinental ballistic-missile program, coordinating the scientific efforts of several firms in this large systems-acquisition program. Ramo, the organizer of the electronic and missile operations for the Hughes Aircraft Company, was also a cofounder of Ramo and Wooldridge, which later merged into TRW, Inc. His association with these companies and his two books applying science to social problems (Ramo, 1969, 1970) placed him in the forefront of systems-engineering associated with computers, missile systems, electronics, transportation, and city planning (Miles, 1973).

While NASA was busy with the Apollo program during the 1960's, the Department of Defense (DOD) was developing a renewed interest in systems acquisition. Part of this interest was generated by the planning, programming, and budgeting system (PPBS) that Secretary of Defense Robert S. McNamara and Dr. Charles J. Hitch had issued (Fabian, 1977).

The PPBS required that military-force components be linked directly to the resources required to support them. This linkage caused an increased emphasis on mission-oriented operational requirements and thereby effected the systems-acquisition process. At the same time, a variety of problems and deficiencies were identified in the DOD systems-acquisition process (Peck and Scherer, 1962).

In the mid-1960's, in response to the PPBS requirements and to the problems identified with systems acquisition, the Air Force's principal development command, the Air Force Systems Command (AFSC), published the 375 series manuals, which set forth the management practices to be used in systems acquisition. *Systems Program Office Manual* (USAF, 1966c) provided an overview and an introduction to the management of the systems-acquisition process. *Systems Program Management Procedures* (USAF, 1966b) established the overall framework, procedures, and objectives for the systems-acquisition life cycle. But it was the third manual, *Systems Engineering Management Procedures* (USAF, 1966a), that set forth an overall systems-engineering approach for systems acquisition, which included defining the problem, establishing the operational requirements, setting the objectives, managing the overall process, periodically reviewing the designs, communicating, and testing and evaluating. The manual stated that developing a system was a multidiscipline task and that these various disciplines needed to be integrated into what is now

called *systems teams*. The following phases of the systems life cycle were identified in this third manual: conceptual, definition, acquisition, and operational phases. Although this manual did not formulate a systems-engineering methodology, the concepts of a systems-engineering approach were clearly outlined.

All the services have continued to pursue their systems-engineering interests as they relate to DOD systems acquisition. The Department of the Navy's *Weapon Systems Selection and Planning* (Navy, 1974) and the Air Force's *Engineering for Defense Systems* (USAF, 1976) are examples of the services' continued interest in an overall systems-engineering approach to systems acquisitions.

The above discussion points out the historical precedent for a relationship between the Defense systems-acquisition process and systems engineering. Such procedures as those set forth in *Systems Engineering Management Procedures* (USAF, 1966a) evolved from the military services, extensive experience in developing and managing highly complex,[1] large-scale systems. The military services have been in the forefront of those using these types of large-scale, complex systems and have dealt with them in a holistic fashion (Hill, 1970).

In this chapter, the Defense systems-acquisition process is discussed in the context of a systems-engineering framework and from the standpoint of the DOD-policy directives

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[1]Hill defined *complex* as, "[A system in which] a change in one variable will affect many other variables in the system, rarely in linear fashion. An equally important characteristic is the existence of multiple feedback loops and feedback loops within feedback loops."

previously mentioned. Those areas wherein the actual procedures used in the systems-acquisition process vary within the DOD-policy framework established by the directives are taken up in the next chapter.

After reviewing the existing systems-engineering approaches, a specific systems-engineering framework is used throughout the remainder of this dissertation. The DOD-policy-directed approach to the systems-acquisition process is then examined to clearly identify its functions, activities, and decision points. Finally, a comparative analysis of the selected steps and phases of a systems-engineering framework and the activities and phases of the Defense systems-acquisition process demonstrate the relationship between the two procedures.

The Systems-Engineering Framework

The following definitions of systems engineering and its purpose are suitable for use with problems of this scope and complexity:

> Systems engineering is an appropriate combination of the mathematical theory of systems and behavioral theory in a useful setting appropriate for the resolution of real world problems. The purpose of systems engineering is to develop policies for the management, direction, and regulation activities relative to the planning, development, production, and operation of total systems to maintain overall integrity. (Sage, 1977c)

Although these definitions can be broadly applied to many systems and policy approaches, the Defense systems and the DOD policy framework governing their acquisition are specifically addressed here.

A methodology is "an open set of procedures which provides the means for solving problems" (Sage, 1977a); a set of tools, a set of proposed activities for problem solution, and a set of relations among the tools and activities constitute a methodology. The tools of systems engineering are words, mathematics, and graphics. These tools, including algorithms and concepts, enable various activities within systems engineering to be carried out. The particular sets of relations among tools and activities that constitute the framework (procedural structure) for systems engineering are of particular importance because such a framework:

1. Does a great deal to enable the handling of the considerations, interrelations, and controversial value judgments of large-scale, complex problems;

2. is of significant value in teaching the policy makers and decision makers the value of the systems approach;

3. allows problems to be resolved at the institutional and value levels as well as at the symptomatic level where so much effort is concentrated.

For a systems-engineering methodology to be developed within a systems-engineering framework, the framework should have the following characteristics:

1. It must be decision oriented to meet the demands of decision makers.

2. It must be broad enough to cover the life-cycle phases of various systems from conception of a need to retirement of the system.

3. It must consider the multidiscipline nature of systems problems.

4. It must incorporate the value system operative in each problem.

5. It must be adaptable and flexible enough to have general application to systems-engineering problems.

The last characteristic is important as it infers the need for a *standard* systems-engineering framework to be applied to large-scale, complex problems. Some systems-engineering methodologies were discussed in the following sources: Arthur D. Hall, III (1962, 1969), Harold Chestnut (1967), Lawrence S. Hill (1970), John E. Gibson (1972, 1973, 1977a, 1977b), Ralph F. Miles, Jr. (1973), Wilton P. Chase (1974), and Vincent P. Luchsinger and V. Thomas Dock (1976). Other methodologies were referenced by Sage (1977a) in an editorial in the *IEEE Transactions on Systems, Man, and Cybernetics*.

In his editorial, Sage discussed the need for a *standard* framework for systems engineering. He persuasively argued the merits of this approach and effectively pointed out the problems that would accrue to systems engineering if a single methodology were not adopted. Sage further proposed the adoption of the comprehensive three-dimensional framework, or morphology, set forth by Arthur D. Hall, III (1969), as the framework within which systems engineering should be practiced. Three dimensions of this morphology are time, logic, and knowledge.

The time dimension, often referred to as the course structure of the morphology, depicted a sequence of activities in the life of the system from its inception to retirement and was segmented into intervals, or phases, by a set of major-decision milestones. The various phases of a system life cycle were (Hall, 1962, 1969):

1. *Program Planning:* the organization identified the activities and projects it would study on more detailed levels of planning. The program was normally large scale, complex, and long term.

2. *Project Planning:* the organization concentrated on one of the several projects of the overall program.

3. *System Development:* planning was implemented; this phase dealt primarily with components rather than with overall alternatives and ended by preparing detailed specifications, drawings, and bills of materials for the manufacturers or construction organization.

4. *Production:* all required activities gave physical embodiment to the system. For a new product, the manufacturing engineers determined the sequence, material flow, and floor layout required, designed the tooling and test jigs, and established quality control.

5. *Distribution:* the system was phased-in and conveyed to the ultimat users. This could involve all kinds of distribution facilities, preparation for support functions, and training for systems maintenance and operation personnel.

6. *Operations:* the system was used or the product consumed. The operational period was the reason for all forms of systems engineering.

7. *Retirement:* the system was taken out of service or the product phased-out.

The second dimension of the systems-engineering morphology was a problem-solving procedure that had several steps to be carried out during each phase of the system's life cycle. These steps were normally conducted in the following sequence (Sage, Warfield, Thissen, *et al.*, 1978):

1. *Problem Definition:* the needs, constraints, and alterables associated with an issue were described and standardized. The purpose of problem definition was to clarify the issues under consideration so that other steps of the systems process could be carried out.

2. *Value Systems Design:* the objectives and objectives measures were determined, as well as the interrelationship between objectives and between objectives and objectives measures and the interaction between objectives and the elements of the problem-definition step.

3. *System Synthesis:* the policies or systems that might satisfy the established need or attain the desired objectives were established. Normative, behavioral, and technological constructs and the transition scenarios for policy alternatives were delineated.

4. *Systems Analysis and Modelling:* models were constructed to determine the consequences of pursuing policies,

i.e., to determine the behavior or subsequent conditions resulting from alternative policies and systems.

5. *Optimization of Each Alternative:* the individual policies or systems were fine tuned often by adjusting parameters to refine each individual policy or system.

6. *Decision Making:* systems or policies were selected (or not selected) for further planning and resource allocation.

7. *Planning for Action:* implementation efforts, resource and management allocations, or plans for the next phase of effort were delineated.

The third dimension referred to the body of knowledge (facts, models, and procedures) used to define a discipline, profession, or technology. Possible disciplines that could be employed within this framework included law, medicine, engineering, and the social sciences.

A single systems-engineering framework is used throughout this study. The three-dimensional morphology box set forth by Arthur D. Hall, III (1969) is adopted as the particular approach to be applied (Figure 5).[2]

Systems-Acquisition Policy and Milestones

The federal government's procurement policies for its executive-branch agencies were set forth by Office of Management and Budget (OMB) in *Major Systems Acquisition* (OMB, 1976)

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[2]This morphology box will be referred to throughout the dissertation as the systems-engineering framework.

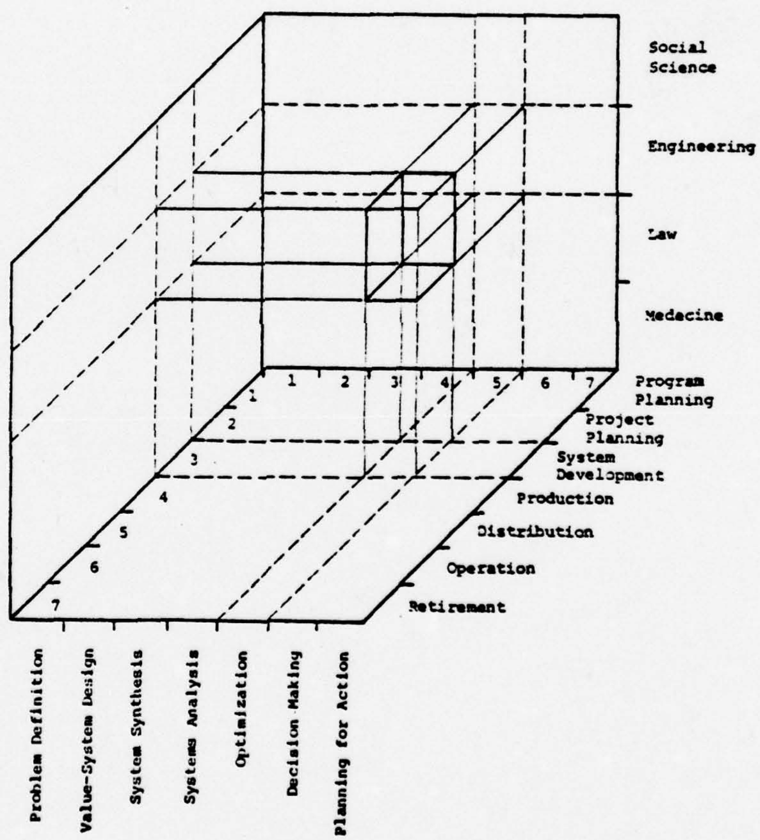

Figure 5. The Morphological Box for Systems Engineering (SOURCE: Hall, 1969).

wherein a major system was defined as

> a combination of elements that will function together to produce the capabilities required to fulfill a mission need (i.e., a required capability within an agency's overall purpose).

To be defined as a major systems-acquisition program a program must be directed at and critical to fulfilling an agency mission, must entail the allocation of relatively large resources, and must warrant special management attention. The circular also provided for the agency head to establish relative dollar thresholds as one of the criteria for determining which programs should be considered as a major systems-acquisition program.

The policies of the circular, which were developed to assure the effectiveness and efficiency of the process of acquiring major systems, are:

1. To express needs and program objectives in mission terms and not equipment terms, to encourage innovation and competition in creating, exploring, and developing alternative systems-design concepts.

2. To emphasize the initial activities of the systems-acquisition process to stress the competitive exploration of alternative systems in response to mission needs. Whenever economically beneficial, the competition between similar or differing systems designs should continue throughout the program.

3. To inform Congress of a major systems-acquisition program immediately after the agency head has approved a new mission need.

4. To establish clear lines of authority, responsibility, and accountability for the management of a major systems-acquisition program by using the appropriate managerial levels in decision making and obtaining agency-head approval at key decision points.

5. To appoint an acquisition executive to be responsible for integrating and unifying the systems-acquisition management process and implementing a monitoring policy. This appointment is to be made by the agency head.

6. To establish a systems-acquisition plan built on an analysis of agency mission needs and an appropriate allocation of resources.

7. To tailor an acquisition strategy for any program, as soon as the agency decides to solicit alternative systems-design concepts, that could lead to the acquisition of a new major system and to refine the strategy throughout the acquisition process.

8. To designate a program manager for each major systems-acquisition program as soon as a decision is made to fulfill a mission need by pursuing alternative systems-design concepts.

Technical and program decisions would normally be made at the level of the agency component or operating activity (program office). However, the policies of *Major Systems Acquisition* (OMB, 1976) provided for the agency head to have control over the agency's major acquisitions by

reserving for him the right to make the key decisions during the systems-acquisition process. These four key decisions were:

1. The approval of a specifically identified and defined mission need, of the relative priority assigned within the agency, and of the general magnitude of resources that may be invested.

2. The selection of competitive systems-design concepts to be advanced to a test or demonstration phase or the authorization to proceed with the development of a noncompetitive (single-concept) system.

3. The commitment of a system to full-scale development and limited production.

4. The commitment of a system to full production.

Each decision is a go or no-go decision and requires the reaffirmation of the prior decision. These decisions were designed to establish concise and well-defined mission needs, to maximize the number of viable system alternatives considered, and to enhance the design and planning efforts. In making these key decisions, the agency head exerts meaningful control over the direction and scope of the systems-acquisition programs within his agency. Using the procedures of Warfield and Hill (1971), a DELTA Chart alternating phases of the systems-acquisition process with the key decisions by the agency head is presented in Figure 6.

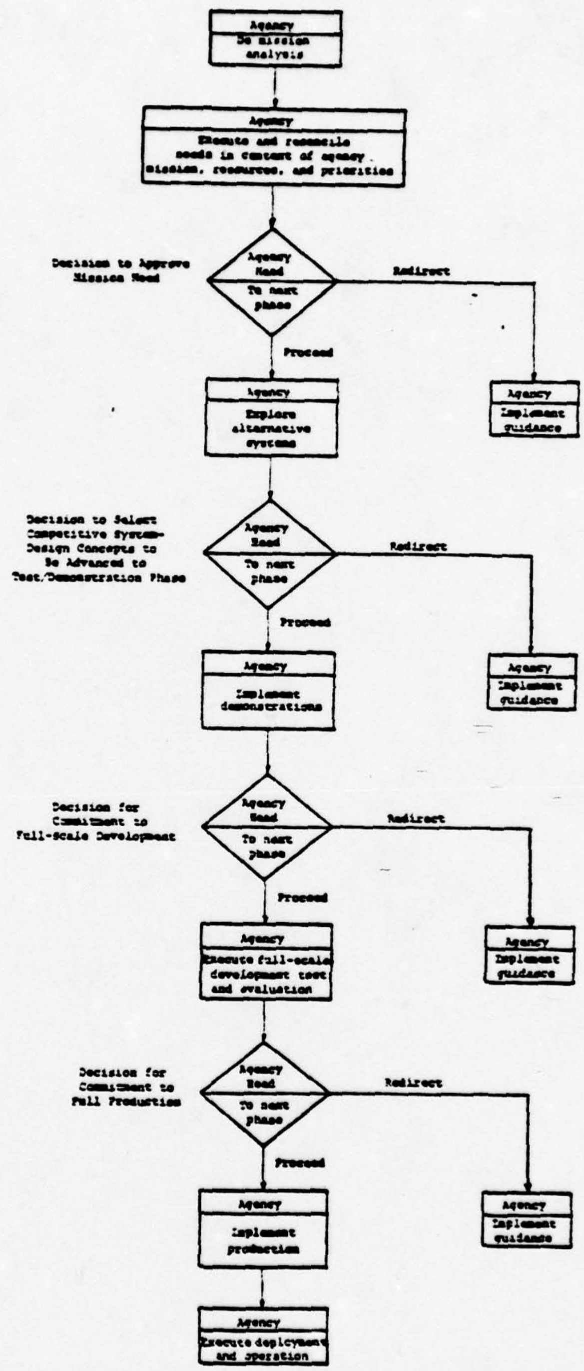

Figure 6. The Major Systems-Acquisition Cycle for Executive Departments.

The policies of the OMB directive (1976) were effected by two revised DOD directives, *Major Systems Acquisition*, (DOD, 1977a) and *Major Systems Acquisition Process*, (DOD, 1977b). Both directives reiterated the policies of the OMB paper and tailored those policies to the DOD. Many policies introduced by the OMB directive for all executive-department agencies were already in place and operative within the DOD.

The first of the two DOD directives presented the overall policies for systems acquisiton within the DOD and established the four major-decision milestones, which the SECDEF, as agency head, must consider. These four major-decision milestones were: Milestone 0--Program Initiation, Milestone I--Demonstration and Validation, Milestone II--Full-Scale Engineering Development, and Milestone III--Production and Deployment. The position of Defense Acquisition Executive (DAE) within the Office of the Secretary of Defense (OSD) was also established for systems-acquisition matters. Among other policies, this first directive also set forth the program manager's responsibilities and his authority, the test-and-evaluation considerations, and the requirement to explore competitive systems-design concepts. Systems programs involving an anticipated cost of $75 million in research, development, test and evaluation (RDT&E) or $300 million in production were identified in the directive as programs to be considered for designation as major systems acquisitions.

The second directive, *Major Systems Acquisition Process*, covered several areas, including, systems-acquisition advisory councils, mission-area-analysis requirements, scheduled program reviews and Secretary of Defense (SECDEF) decision making, program management considerations, major systems-program documentation, and program issues to be addressed at each of the major-decision milestones. Provisions were made in this directive for the establishment of two advisory councils: The Defense Systems Acquisition Review Council (DSARC) and the (Service) Systems Acquisition Review Council ([S]SARC). The DSARC was established to advise the SECDEF on the major-decision milestones for systems-acquisition programs. The DAE is the chairman of the DSARC and its members are senior management officials from OSD. Prior to each major-decision milestone, the DSARC must review the program under consideration and make recommendations to the SECDEF on the program.

The (S)SARC functions similarly to the DSARC but at the service-headquarters level. The (S)SARC has senior management officials as its members and must meet prior to each major-deicsion milestone to review the program under consideration. As a result of this review, the (S)SARC makes recommendations on the program to the Service Secretary (SERVSEC).

The second DOD directive also stipulated that two major documents be submitted for proposed and approved systems programs to support the DSARC and (S)SARC reviews and decisions of the Secretary of Defense: the Mission Elements Need

Statement (MENS) and the Decision Coordinating Paper (DCP). The MENS must identify the mission need in terms of the task to be performed. An assessment of the projected enemy threat through the time frame of the capability must be presented in the MENS and the existing DOD capability to accomplish the mission must be identified. Constraints dealing with operational, logistical, and NATO standarization must be stated in the MENS, with an assessment of the impact of not acquiring the capability. A program plan to examine competitive alternative systems and to establish a systems program office must also be presented in the MENS. Upon completion, this document must be submitted to the SECDEF by the component head for the Milestone 0 decision.

The Decision Coordinating Paper must be prepared by the DOD component and must summarize the program. Its principal purpose is to support the DSARC and (S)SARC reviews and the decisions that the SECDEF must make at the Milestone I, II, and III major-decision points. The content and issues documented by each DCP should accurately and completely reflect the program while focusing on the particular program phase that is the subject of the SECDEF's upcoming actions. The DCP must include an approved MENS, descriptions of alternative programs, a summary of the acquisition strategy, business-planning information, program-management plan, areas of program uncertainty, required resources of each alternative, a logistics annex, and test-and-evaluation (T&E) planning, and status data. The results of DSARC and

(S)SARC reviews and the SECDEF's previous decisions and directions must also be included in the DCP.

A DELTA chart documenting the DCP-approval cycle is presented as Figure 7. The cycle begins with the SECDEF's decision that was documented in a DCP and ended the previous phase. His decision has resulted in an update of the PPBS and a program-management directive for the systems-program office. The systems-program office then carries out the next phase of the systems-acquisition process, culminating in the recommendations to be developed for the next phase. These recommendations are then given to the service headquarters to develop a draft DCP. Next, the draft DCP is reviewed by the (S)SARC and recommendations made to the Service Secretary. The Service Secretary then takes the appropriate action on the DCP and forwards it to the DAE and DSARC; the DSARC makes its recommendations to the SECDEF. Finally, the SECDEF takes action on the DCP and issues his decision, thus completing the cycle.

DOD directive 5000.2, *Major Systems Acquisition Process*, set forth the phases, scheduled program reviews, and SECDEF major-decision milestones that make up the major systems-acquisition process. A DELTA Chart representing this process is presented as Figure 8. As depicted by this chart, the systems-acquisition process begins with a continuing mission analysis by the service that can result in the identification of one or more mission needs. A formal MENS

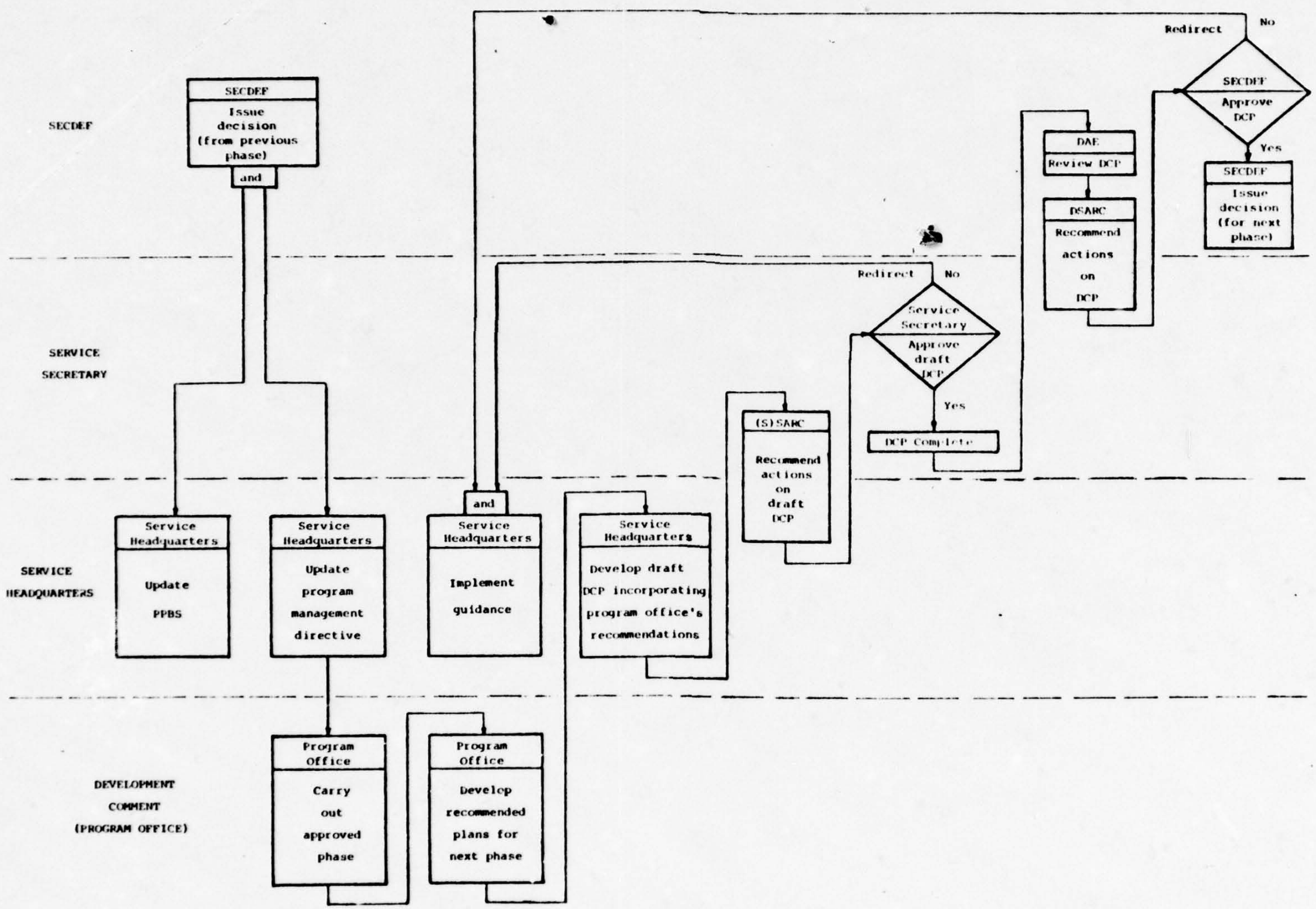

Figure 7. Decision Coordinating Paper (DCP) Approval Cycle.

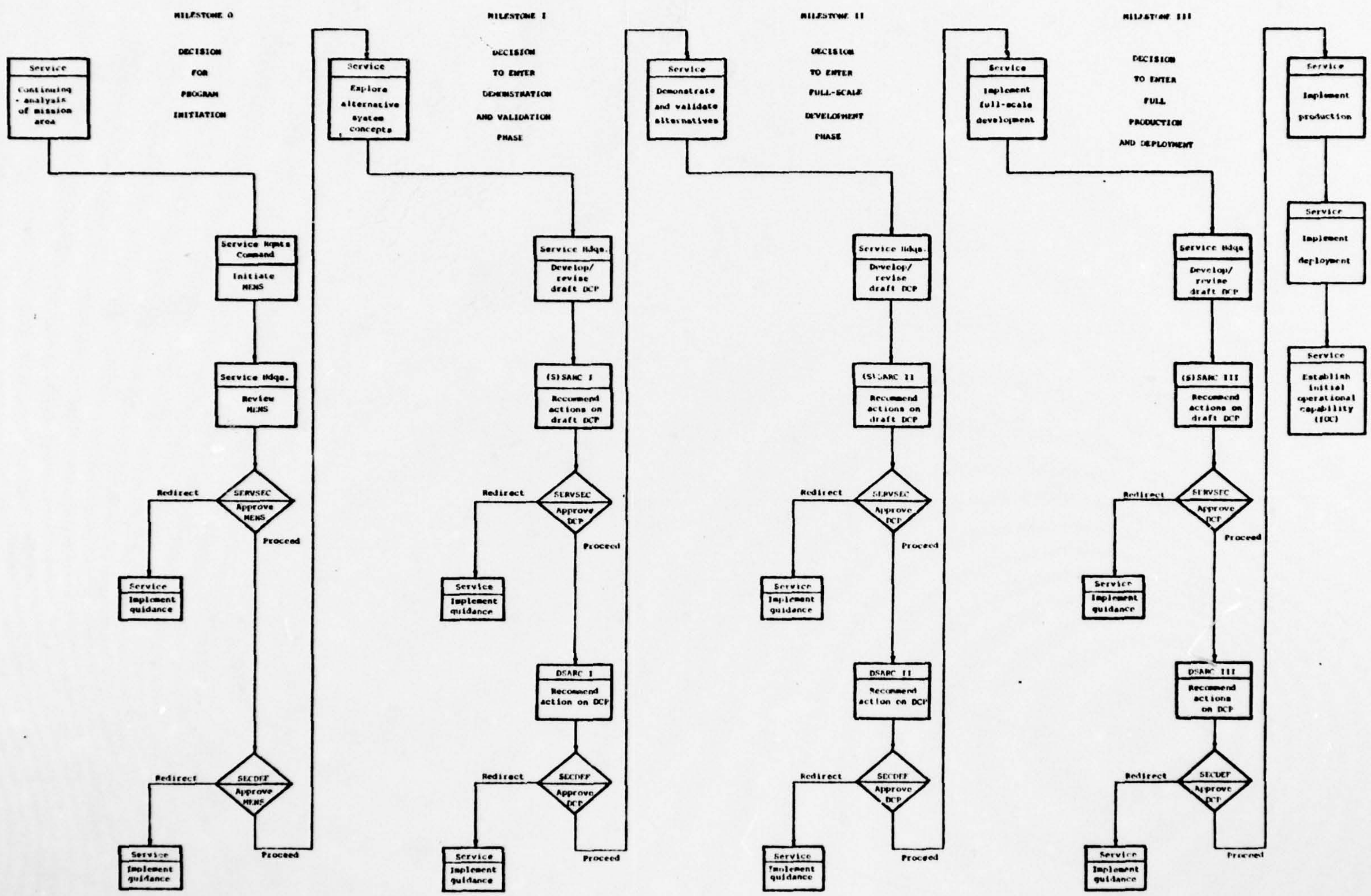

Figure 8. The DOD Systems-Acquisition Process for Major Systems.

is then submitted for the approval of Service Headquarters, the Service Secretary, and the SECDEF. Once the SECDEF's approval has been secured for program initiation, the program moves to the conceptual phase. When the work of the conceptual phase has been completed by the program office, a draft DCP is developed by the service headquarters. The DCP is then carried through the DCP-approval cycle (Figure 7). The successive phases of the process, demonstration and validation and full-scale-engineering development then proceed. Each phase is followed by a DCP-approval cycle culminating in a major-decision milestone by the SECDEF. The final decision approves the system for production and deployment. As production proceeds, more items are fielded, resulting in an initial operational capability (IOC) for the service.

An analysis of the several steps in each phase of the systems-acquisition process is presented in the next section of this chapter.

The Phases of the Systems-Acquisition Process

The top-level DOD policies for systems acquisition were presented in the two DOD directives previously mentioned (DOD, 1977a,b). These policies are implemented within the services by each headquarter's issuing its own systems-acquisition-policy directives. A brief summary of these individual directives is presented here.

The Air Force has one directive, *Acquisition Program Management* (USAF, 1977), to implement the DOD directives and another *Statement of Operational Need* (USAF, 1978) to develop the operational-needs documentation, specifically the MENS. The Department of the Navy has *Systems Acquisition in the Department of the Navy*, and *Systems Acquisition Process in the Department of the Navy* (Navy, 1978a,b); the Army has *Basic Policies for Systems Acquisition* and *Systems Acquisition Review Council Procedures* (Army, 1978 a,b); and the Marine Corps has *Systems Acquisition Management Manual* (Navy, 1979) to implement the DOD policies.

The policies of the four services outlined in the several directives above are different in their approaches; they vary in the level of detail presented and in the actual procedures to be followed within each service. However, there are areas common to each acquisition approach, which are discussed in this section. Each of the four major phases of the systems process are examined here to identify those activities that make up each phase and that must be carried out to comply with the two DOD directives. A general description of each activity is presented.[3]

The first phase to be examined to determine its basic activities is the one preceding the program-initiation decision. During this phase, the mission area to be analyzed

[3]For a more definitive description of the detailed procedures of the several phases, see *Project Manager's Guide* (Navy, 1977).

is decided and the MENS is developed. DOD Directive 5000.2 *(Major Systems Acquisition Process)* set forth the purpose of the MENS. These requirements were amplified by the Under Secretary of Defense, Research and Engineering, in his memorandum *Mission Element Need Statement* (Defense, 1978). This memorandum outlined the MENS and explicitly established its role in the systems-acquisition process.

The development of a MENS depends on three activities that must be carried out on a continuing basis: First, that area of the Defense mission that the service involved is responsible for must be effectively analyzed. Second, the service must be cognizant of the existing and planned capabilities that could be used to fulfill a particular mission-element need. Third, intelligence agencies must carry out the threat assessments related to the mission area under consideration.

The continuous performance of these three activities is critical to the accomplishment of the mission-area-analysis phase of a systems-acquisition process. Considering these activities as the foundation for the phase, the activities, or the steps, necessary to carry out the analysis for the phase and their normal sequence of accomplishment are as follows:

1. *Define the Mission Need* by identifying the problem and the constraints and relating the desired need to other needs and to existing or projected programs.

2. *Identify Mission Need in Terms of Mission-Element Tasks* by establishing the mission need in a hierarchy of goals or objectives for the mission area. The top-most goals would be heavily value laden while the lower level goals would be more concrete, objective, and quantifiable.

3. *Identify Known-Solution Candidates* by identifying existing and planned capabilities that could be used to fulfill the mission-element need. Not acquiring any capability is clearly a viable option at this point.

4. *Develop Enemy-Threat Scenarios* by modelling the threat over the time for which a capability is required by quantifying the numbers and performance characteristics of the threat.

5. *Assess the Impact of Not Acquiring the Capability* to determine if a recommendation should be made to approve the MENS and thereby initiate a program. If the need is not acquired, then the existing capability must be evaluated against the threat; if the need is acquired, then its impact on manpower, training facilities, force size, and NATO considerations must be evaluated. This overall effort should culminate with the development of the MENS by service headquarters.

6. *Staff and Process MENS* (Milestone 0, MENS Approval Cycle) through the several headquarters and to the SECDEF for his possible approval. This is the program-initiation decision.

7. *Implement the Conceptual Phase* by establishing a plan to carry out the next phase, if the MENS is approved by the SECDEF; identify the overall resources and the schedule to meet Milestone I. A systems-program office should be included in the planning.

The several activities for the mission-area-analysis phase have been incorporated in the DELTA chart of Figure 9. This chart includes a feedback loop for the phase that illustrates the iterative nature of the analysis effort. Personnel from several different disciplines are required to carry out the activities of this phase. These personnel could include mission-oriented operational personnel, operations analysts, intelligence analyists, engineers, research and development specialists, manpower planners, and logistics experts.

The second phase for which the basic activities are determined is the conceptual phase. From the decision-making standpoints of the service headquarters and the OSD, the principal physical output of this phase is the DCP and its associated support documents. Although the DCP has no intrinsic value of its own, it does motivate, justify, and establish a particular program. DOD Directive 5000.2 (Defense, 1977b) set forth the purpose of the DCP, indicated what it should accomplish, and established the issues that should be addressed at each major-decision milestone.

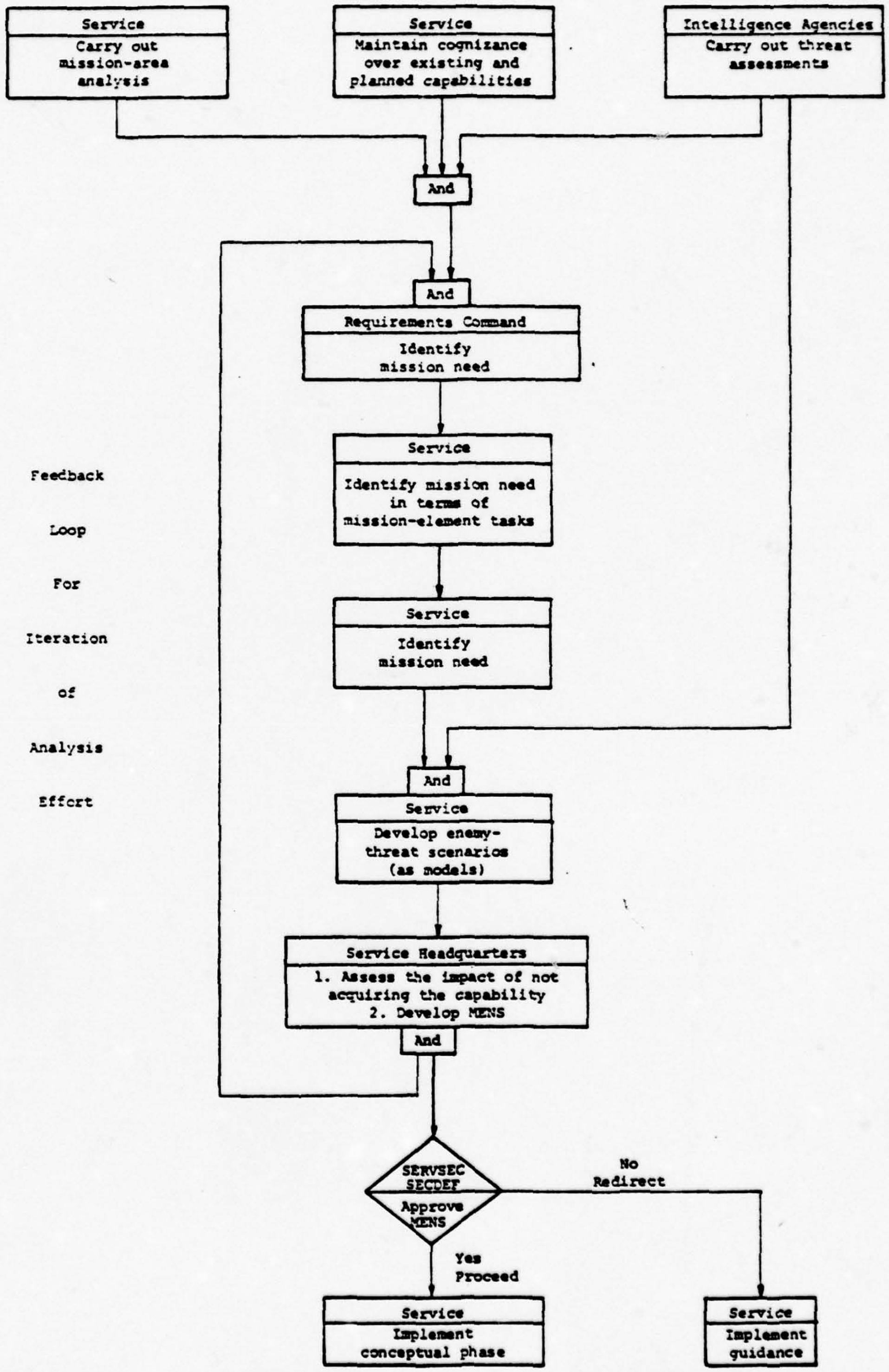

Figure 9. The Activities of the Mission-Area-Analysis Phase of the Systems-Acquisition Process.

The three activities needed to carry out the conceptual phase are the service's continuing mission-area analysis, the establishment of the implementation plan from the previous phase, and the development of the technology base by industry, government laboratories, and academic institutions. The activities or steps required to carry out the analysis of the conceptual phase and their normal sequence of accomplishment are:

1. *Define the Acquisition Problem* by identifying program constraints of all types and the resources limitations, including funding, manpower, and facilities, and by determining the interactions with current or projected programs. The relationship of the mission-element need to the threat and any other considerations should be reaffirmed.

2. *Identify Program Goals and Objectives* by tracing them to the mission element need and by viewing this need in a hierarchy of goals associated with the overall mission area.

3. *Identify Alternative Candidate Systems* by determining acceptable candidate solutions. Alternatives should be competitive yet responsive to the mission-element need. Proposals for candidate solutions could be received from industry, academic institutions, or government laboratories.

4. *Develop Models* through evaluating operational considerations and acquisition approaches. A wide variety

of model types should be considered for use. Risk factors should be considered in developing the models.

5. *Evaluate Alternative Candidate Systems* by using the models to carry out cost-performance tradeoffs to identify one or more alternative systems for consideration in the demonstration and validation phase.

6. *Proceed or Not to the Validation and Demonstration Phase* (Milestone I Decision Point) by carrying out DCP approval cycle (as outlined in Figure 7).

7. *Implement the Demonstration and Validation Phase* by establishing a plan necessary to carry out the next phase. For example, the test program and the acquisition strategy must be carefully planned and coordinated.

The several activities for the conceptual phase are incorporated in the DELTA chart of Figure 10, which includes a feedback loop to indicate the iterative nature of the analysis effort. Many disciplines are necessary for this phase and could include the following personnel: engineers, mission-oriented operational personnel, logistic-oriented personnel, contract lawyers, businessmen, management scientists, operations analysts and intelligence personnel, and financial management personnel.

The third phase for which basic activities must be identified is the demonstration-and-validation phase. Again from the top-level decision-making standpoint, the physical output of this phase is the DCP and its supporting documents.

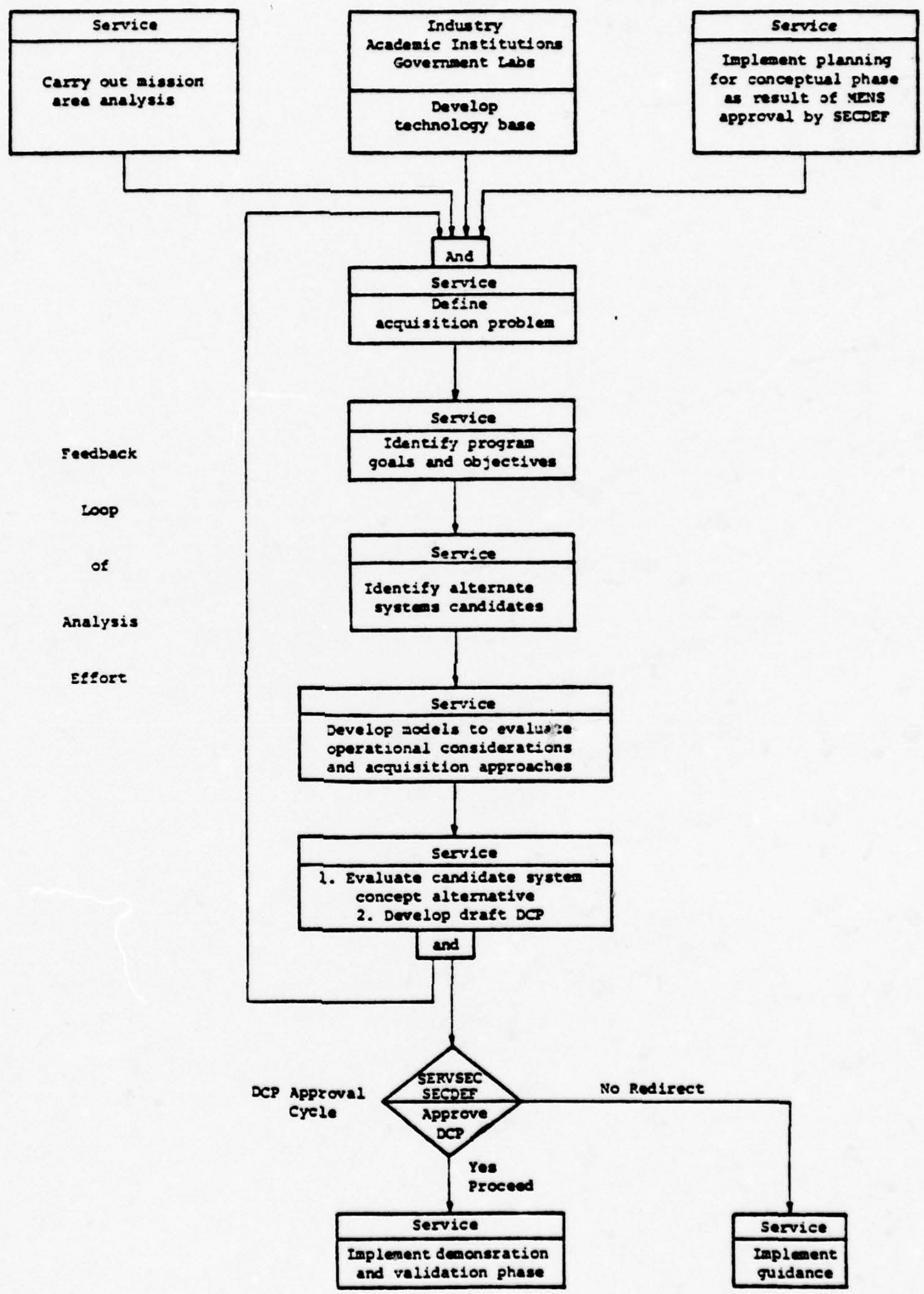

Figure 10. The Activities of the Conceptual Phase of the Systems-Acquisition Process.

As noted above, the DCP's true value lies in its capability to effectively present the system and its status. The mission-area analysis continues in this phase but is primarily used to validate the identified mission-element need. The activities of this phase are similar to those of the conceptual phase but are carried out in greater depth and more detail. The planning from the previous phase (step 7) is used to implement this phase.

The activities that are required to carry out the analysis of the demonstration and validation phase and their normal sequence of accomplishments are:

1. *Define the Systems Problem* by reviewing the problem in light of the further insight gained during the conceptual phase and by examining, in depth, the operational and technical aspects of the problem. Constraints, interactions, and alterable components should be reviewed and then validated or revised.

2. *Examine and Validate Program Goals and Objectives* by tracing them to the mission-element need. More concrete and objective goals should be established as the program proceeds through the acquisition process.

3. *Validate and Refine Systems or Program Alternatives* by analyzing the alternatives from the conceptual phase to determine critical systems-effectiveness parameters. This is usually done by contract with an industry or government

laboratory. Major characteristics (technique, cost, and schedule) of the alternatives become more readily identifiable.

4. *Develop Models* for evaluating systems or program alternatives; i.e., procure and test an advanced development model (ADM). All types of models, such as, simulation, breadboard, and mathematical system-reliability models, may be used in this step.

5. *Evaluate System or Program Alternatives* by using the models from the previous step (step 4) to evaluate the alternatives so that the relationship between systems performance and technical capabilities can be optimized while considering the constraints, such as, force-structure and funding. The goal of this phase is to recommend the most desirable systems design for full-scale development. The results of development, test, and evaluation (DT&E) carried on during this phase provide a significant input to this process.

6. *Proceed to Full-Scale Development* (Milestone II Decision Point) by carrying out the DCP approval cycle as outlined in Figure 7.

7. *Implement the Full-Scale Development Phase* by establishing the plan necessary to carry out the next phase. For example, the test program and the acquisition strategy must be carefully planned.

The several activities for the demonstration-and-validation phase are incorporated in the DELTA chart of

Figure 11, which includes a feedback loop to indicate the iterative nature of the analysis effort. Again, personnel from many disciplines should be employed in this phase.

The final phase to be examined is that of full-scale development. As before, the end product of the phase will be the DCP and its supporting documents presenting the program or system. Certainly the full-scale-engineering test model is important but the emphasis here is on the decision process and the DCP's relation to it. Mission-area analysis continues in this phase as a means to validate the mission need. The planning from the previous phase (step 7) is used to implement this phase.

The following activities to be carried out by the service for this phase are presented in their normal sequence:

1. *Define the Production Problem*, in depth, through a detailed engineering analysis, including the technical and operational constraints and all facets of such factors as the NATO standardization and interoperability requirements.

2. *Examine and Validate Program Goals and Objectives* by tracing the top-level goals through the system design to the actual system components considering the mission area and the threat. Each system component should contribute upward (through subsystems and the system itself) to the stated mission need.

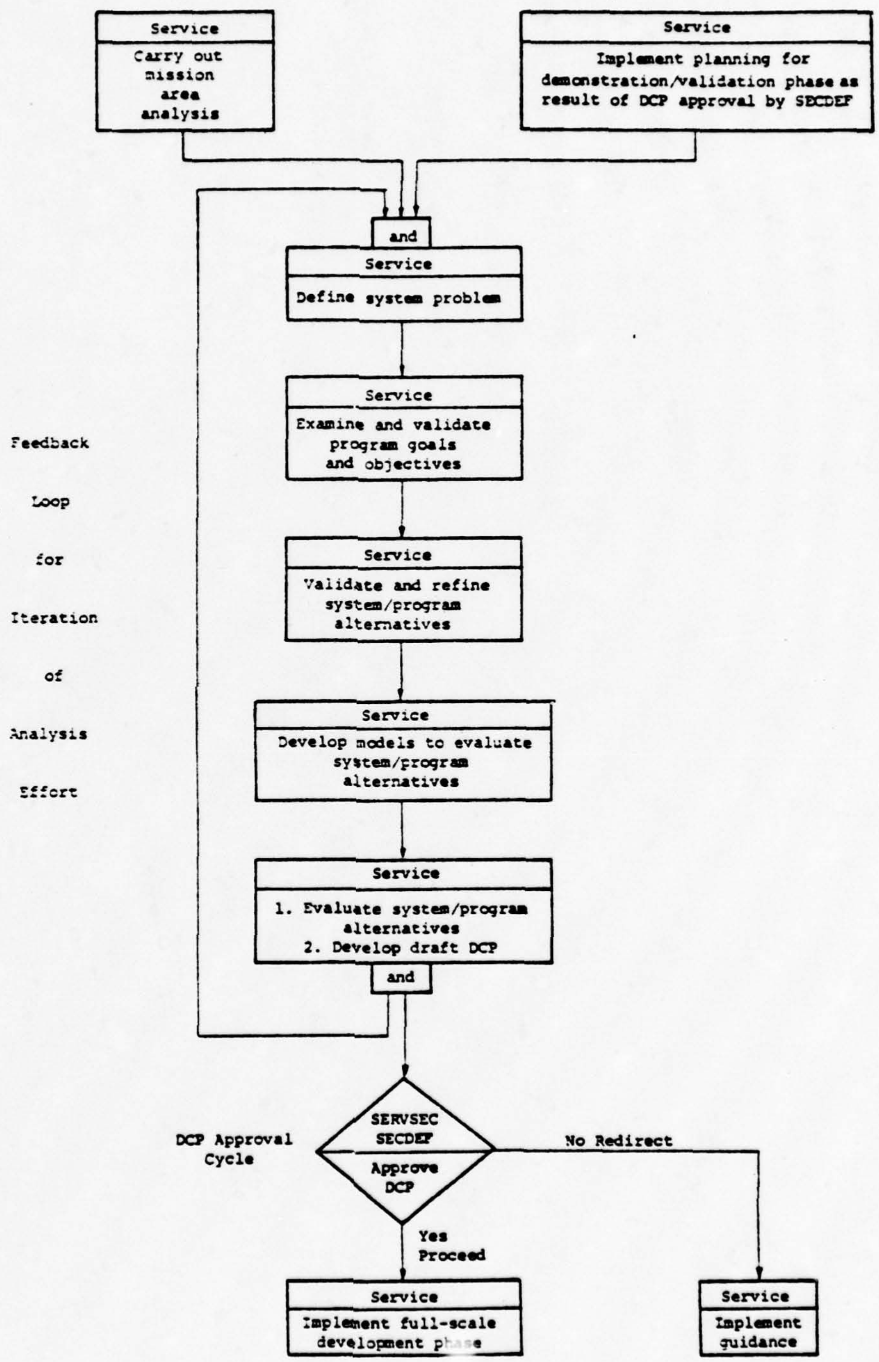

Figure 11. The Activities of the Demonstration-and-Validation Phase of the Systems-Acquisition Process.

3. *Validate the Projected Alternative Systems* to insure that the cost, schedule, and performance goals are being met by the system design. This validation relates primarily to the system itself and not to the mission need.

4. *Develop Models* for evaluating the projected system by relating it to the mission need. The characteristics of the production item should be compared to the mission need in a constrained environment, such as, cost restrictions, personnel, and maintenance, and training requirement difficulties. As before, all types of models may be used in this step.

5. *Evaluate the System* by using the models developed in the previous steps (step 4) to test and evaluate the system so that a substantiated go/no-go recommendation may be made for the production of the system. Initial operational test and evaluation (IOT&E) of the system itself is most commonly used.

6. *Proceed to the Production and Deployment Phases* (Milestone III Decision Point) by carrying out the DCP approval cycle as outlined in Figure 7.

7. *Implement Production and Deployment* by establishing the necessary plans for carrying out the next two phases. Parts of this planning phase will have begun as early as the conceptual phase, and production is heavily dependent on the planning of the previous phases.

The several activities for the full-scale-engineering development are incorporated in the DELTA chart of Figure 12, which includes a feedback loop indicating the iterative nature of the analysis effort. Although the same disciplines mentioned before would be employed in this phase, there would be a greater emphasis here on the design-engineering and manufacturing disciplines. Mission-oriented operational personnel and personnel from the intelligence community would be necessary during the program for the mission-area analysis continuously conducted during the acquisition cycle.

A review of the DELTA charts (Figures 9 through 12) reveals an analysis effort that is generally sequential in nature and may be iterative as more complete and refined information is gained through analysis. The activities shown on the charts can be affected by other activities or events outside each analysis cycle. However, the primary interest here is to show the general flow of the analysis effort as it is observed from the OSD and service-headquarters level. A variety of contractor and government organizations may contribute to the accomplishment of each of the activities. But, because the systems-program office is the focal point for all program matters, the term *service* is normally used in each activity box to show the responsibility to accomplish that activity.

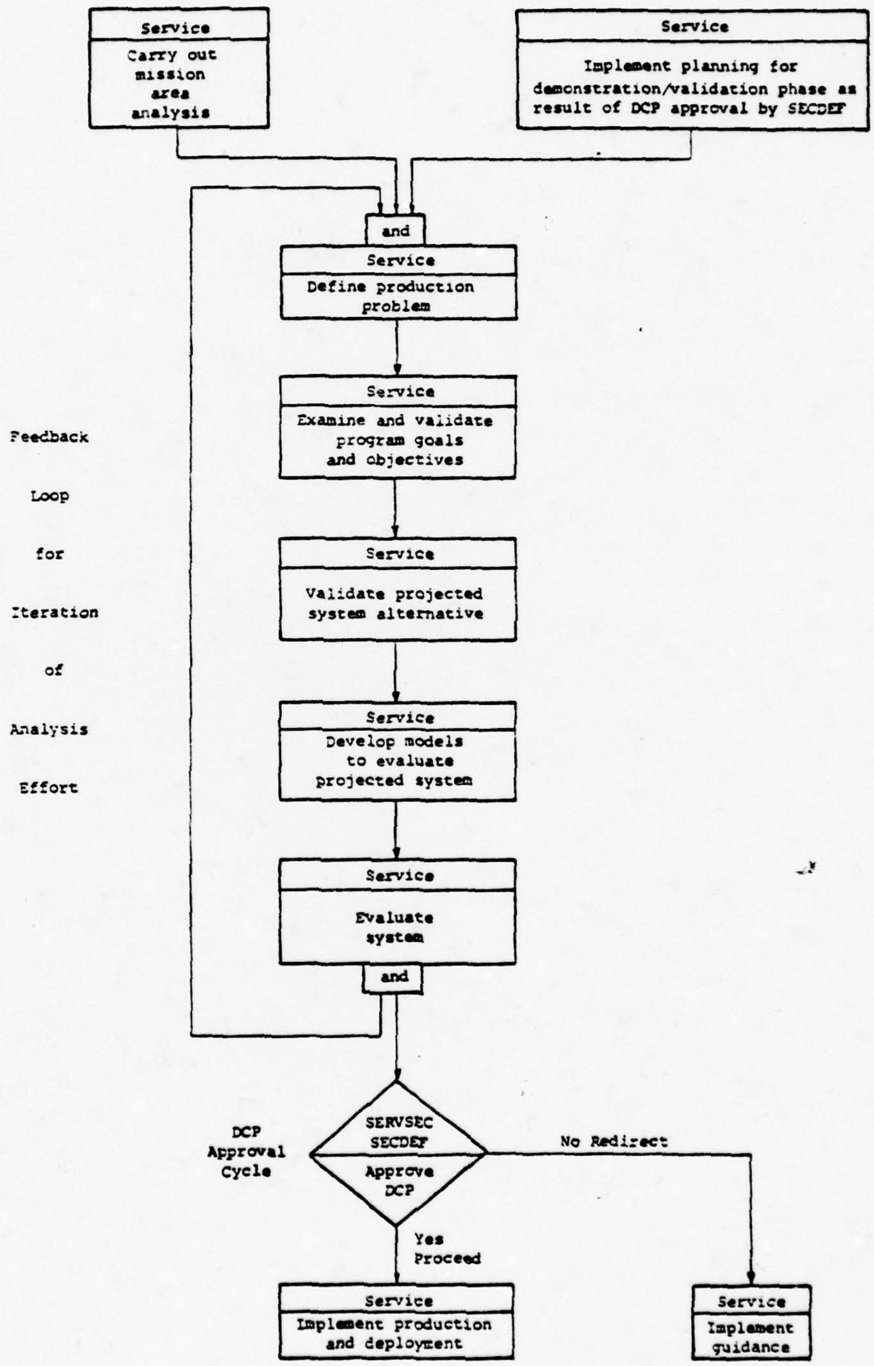

Figure 12. The Activities of Full-Scale Development Phase of the Systems-Acquisition Process.

In the next section the activities in each acquisition-process phase are compared to the steps of the systems-engineering framework.

The Systems-Engineering Framework and the DOD Systems-Acquisition Process

This section examines a possible correlation between the systems-engineering framework (Section, p.67) and the phases of the systems-acquisition process (Section, p. 84). The phases of the framework and the steps of each phase will be examined.

The phases of the systems-engineering framework are almost equivalent to the phases in the Defense systems-acquisition process. A review of Table 1 shows that, with one exception, there is a one-to-one correspondence between the phases of the two classification systems; the exception is the phase termed *project planning* by Hall (1969). For this phase, two comparative phases may be identified in the Defense systems-acquisition process--the conceptual phase and the demonstration-and-validation phase. The activities of each phase (conceptual and demonstration and validation) are equivalent to the systems-engineering project-planning phase, except that the demonstration-and-validation phase is carried out in greater depth and in a more definitive fashion than the conceptual phase. These two phases can be considered separate entities within the systems-engineering framework without any loss of generality. The time dimension of the

TABLE 1

COMPARISON OF THE TIME-DIMENSION PHASES OF THE SYSTEMS-ENGINEERING MORPHOLOGY WITH THE PHASES OF A SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Dimension Phases[1]	Systems-Acquisition Phases[2]	Comments
Program planning	Mission analysis and the development of a MENS	Concern is for roles and and missions; activities and goals are identified.
Project planning	Conceptual Demonstration and validation	Emphasis is on a specific project; identification, cultivation, evaluation of viable candidate solutions are main concerns.
System development	Full-scale development	The system and principal items necessary for support are designed, fabricated, tested; concern is for system components, not system alternatives.
Production	Production	The functions performed are the same.
Distribution	Deployment or phase-in	Both overlap with operation phase, but functions performed are the same.
Operation	1. Operation/support 2. Maintenance/repair 3. Modification/ retrofit	Several activities occur in parallel during this phase.
Retirement	Retirement or phase-out	Both overlap with the operation phase.

[1]See *The Systems-Engineering Framework* (p.67).

[2]Systems-acquisition phases are defined in Appendix A (p.325).

systems-acquisition process is conveniently and properly modelled using the systems-engineering framework. The comments column of Table 1 further compares the two classification systems.

The logic dimension steps as presented in *The Systems-Engineering Framework* (p. 67) have also been compared to the several activities of each phase of the systems-acquisition process (Section, p. 84). These comparisons are presented in Tables 2, 3, 4, and 5 for the mission-analysis phase, conceptual phase, demonstration-and-validation phase, and full-scale-development phase, respectively. Each indicates a favorable comparison between the logic dimension steps of systems engineering and the activities of each systems-acquisition phase. The logic steps of the systems-engineering morphology provide an appropriate approach for modelling the activities of each phase in the systems-acquisition process.

An overall review of the results presented in Tables 1 through 5 shows that the phases of a systems-acquisition process closely align themselves with the phases of the systems-engineering framework. This is consistent with findings that indicate research-and-development programs could be viewed as having multistage (or multiphase) aspects (Brandenburg and Langenberg, 1969; Gear, Lockett, and Pearson, 1971; Gear and Lockett, 1973, 1978). Additionally, Albala (1975) indicated an interrelationship between the phases of a

TABLE 2

COMPARISON OF THE LOGIC-DIMENSION STEPS OF THE SYSTEMS-ENGINEERING MORPHOLOGY WITH THE ACTIVITIES OF THE MISSION-ANALYSIS PHASE OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Logic-Dimension Steps[1]	Mission-Analysis Activities	Comments
Problem definition	Mission-need identification	An operational need statement is developed; includes deficiencies, constraints, existing and planned capabilities, problem interrelationships.
Value-system design	Identify mission need in terms of mission-element tasks	Top-level objectives are determined; objectives measures are identified.
Systems synthesis	Identify known solution candidates	Candidate policies or capabilities are postulated; includes existing DOD capability and no system.
Systems analysis and modelling	Develop enemy-threat scenarios for time frame of required capability	Threat scenarios are used to model enemy capabilities.
Optimization	Assess impact of not acquiring or maintaining capability	Candidate solutions are considered in context of the threat, projected obsolescence, technological opportunity.
Decision-making	Milestone 0 (MENS approval cycle)	MENS is processed through Requirements Command, Service Headquarters, SERVSEC, DAE, SECDEF.
Planning for action (implementation of next phase)	Implementation/ conceptual phase	Plan includes identifying, exploring competitive alternative systems, establishing systems-program office.

[1]See *The Systems-Engineering Framework* (p. 67).

TABLE 3

COMPARISON OF THE LOGIC-DIMENSION STEPS OF SYSTEMS-ENGINEERING MORPHOLOGY WITH THE ACTIVITIES OF THE CONCEPTUAL PHASE OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Logic-Dimension Steps[1]	Conceptual-Phase Activities	Comments
Problem definition	Define acquisition problem	Missions-element task is reaffirmed in enemy-threat context; program constraints are identified.
Value-system design	Identify program goals and objectives	Goals are traceable to mission-element need.
Systems synthesis	Identify candidate-system alternatives	Candidates satisfy mission-element needs, reflect technology base, and provide acceptable environment; all alternatives are considered.
Systems analysis and modelling	Develop models to evaluate operational consideration and acquisition approaches	Cost-performance tradeoffs and logistics are considered; capability to handle risk factors is incorporated.
Optimization	Evaluate candidate-system alternatives	Models developed in the previous step are used.
Decision making	Milestone I (DCP approval cycle)	DCP is processed through (S)SARC, SERVSEC, DAE, DSARC, SECDEF.
Planning for action (implementation of next phase)	Implementation of demonstration-and-validation phase	Plan includes test program for next phase, acquisition strategy, business planning to support acquisition strategy.

[1]See *The Systems-Engineering Framework* (p. 67).

TABLE 4

COMPARISON OF THE LOGIC-DIMENSION STEPS OF SYSTEMS-ENGINEERING MORPHOLOGY WITH THE ACTIVITIES OF THE DEMONSTRATION-AND-VALIDATION PHASE OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Logic-Dimension Steps[1]	Demonstration-and-Validation-Phase Activities	Comments
Problem definition	Define systems problem	Technical approaches from conceptual phase are analyzed. Constraints and needs are identified in context of operational and technical considerations.
Value-system design	Examine and validate program goals and objectives	Goals are traceable to mission-element need and extend to quantifiable levels; technical considerations are included.
System synthesis	Validate and refine	Technical approaches from conceptual phase are validated; system is redefined and critical parameters identified.
Systems analysis and modelling	Develop models to evaluate system or program alternatives	Models developed to evaluate system effectiveness.
Optimization	Evaluate system or program alternatives	Analysis, simulation, or advance development determine optimal relationship between operational requirements, technical capabilities; DT&E results are considered.
Decision making	Milestone II (DCP approval cycle)	DCP is processed through (S)SARC, SERVSEC, DAE, DSARC, SECDEF.
Planning for action (implementation of next phase)	Implementation of full-scale-development phase	Plan includes test program for next phase, updated acquisition strategy, business plan to support strategy.

[1]See *The Systems-Engineering Framework* (p.67).

TABLE 5

COMPARISON OF THE LOGIC-DIMENSION STEPS OF SYSTEMS-ENGINEERING MORPHOLOGY WITH THE ACTIVITIES OF THE FULL-SCALE-DEVELOPMENT PHASE OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Logic-Dimension Steps[1]	Full-Scale Development-Phase Activities	Comments
Problem definition	Define production problem	System-production problem is analyzed in depth; operational constraints are reviewed; cost, schedule, risk identified; NATO and interoperability requirements considered.
Value-system design	Examine and validate program goals and objectives	Mission-element need is reaffirmed in context of threat; top-level goals are traceable to subsystems, functions, specifications, system components.
System synthesis	Validate projected system alternative	System undergoing full-scale development is validated; cost, schedule, performance are insured.
Systems analysis and modelling	Develop models to evaluate projected system	Cost models for LCC estimates; simulation, mathematical models for maintainability, reliability, availability considerations; IOT&E for the system.
Optimization	Evaluate system	Above models evaluate system; IOT&E results insure system satisfies mission-element need; system is confirmed cost-effective.
Decision making	Milestone III	DCP is processed through (S)SARC, SERVSEC, DAE, DSARC, SECDEF.
Planning for action (implementation of next phase)	Implementation of production and deployment phase	Plan includes updated acquisition strategy, business plan to support strategy; production plan for facilities, quality control, second source.

[1]See *The Systems Engineering Framework* (p. 67).

development program and the major decisions associated with the program. This is clearly the case in the Defense systems-acquisition process, as indicated by the results presented in Table 2 through 5.

The knowledge aspects of the systems-engineering approach are readily identifiable in the systems-acquisition process. As pointed out in *The Phases of the Systems-Acquisition Process* (p.84), the Defense development programs require personnel from many disciplines to effectively carry them out.

Summary and Conclusions

This chapter has analyzed the structure of the Defense systems-acquisition problems. Initially, the systems-engineering framework was reviewed; the significant aspects of the DOD systems-acquisition policy and the major-decision milestones related to the DSARC process were then covered. The various activities and steps that make up the several phases of the systems-acquisition process were analyzed. Finally, the steps, phases, and knowledge dimensions of the systems-engineering framework were respectively compared to the phases, activities, and discipline requirements of the systems-acquisition process to determine if there is a pairwise correlation between the elements of the three sets.

Based on the analysis in this chapter and, in particular, on the correlations identified in *The Systems-Engineering Framework and the DOD Systems-Acquisition Process* (p.100), the following conclusions are drawn:

1. That the systems-acquisition process is multi-discipline in nature and is representative of systems-engineering problems in its knowledge-requirements dimension.

2. That the time dimension of the systems-acquisition process, represented by its phases, generally approximates the time dimension and phases of the systems-engineering framework.

3. That the logic dimension of the phases of the systems-acquisition process include a sequence of activities (or steps) that are comparable to the steps (or activities) of the logic dimension of the systems-engineering framework.

4. That, given conclusions 1 through 3 above, the systems-acquisition process is the systems-engineering problem that can be carried out within the conceptual framework of the systems-engineering morphological box. Furthermore, the tools and techniques of systems engineering can be applied to the systems-acquisition process in accordance with currently accepted practice (see Hall, 1962; Chestnut, 1966 and 1967; Warfield, 1976; Sage, 1977a, 1977b; Gibson, 1977a, 1977b, 1979).

Therefore the systems-engineering morphological box is used to model the systems-acquisition process throughout

the remainder of this paper. Figure 13 presents the three-dimensional framework for systems engineering that has been revised to incorporate those aspects of the systems-acquisition process previously identified as being peculiar to that process.

Throughout the course of this research a number of DOD personnel were interviewed (see Appendix B, p.334) in relation to the systems-acquisition process. Additionally, a great number of DOD directives and other documents were reviewed.

Based on these sources, it is the author's perception that the DOD personnel currently involved in the system-acquisition process often do not view the process in the context of the systems-engineering framework. Many do not see the overall comparison between a systems-acquisition process and the systems-engineering framework. They do not perceive the parallelism between the several phases of the systems-acquisition process with their comparable activities and decision points. This is particularly true of the mission-analysis (program-planning) phase of the systems-acquisition process.

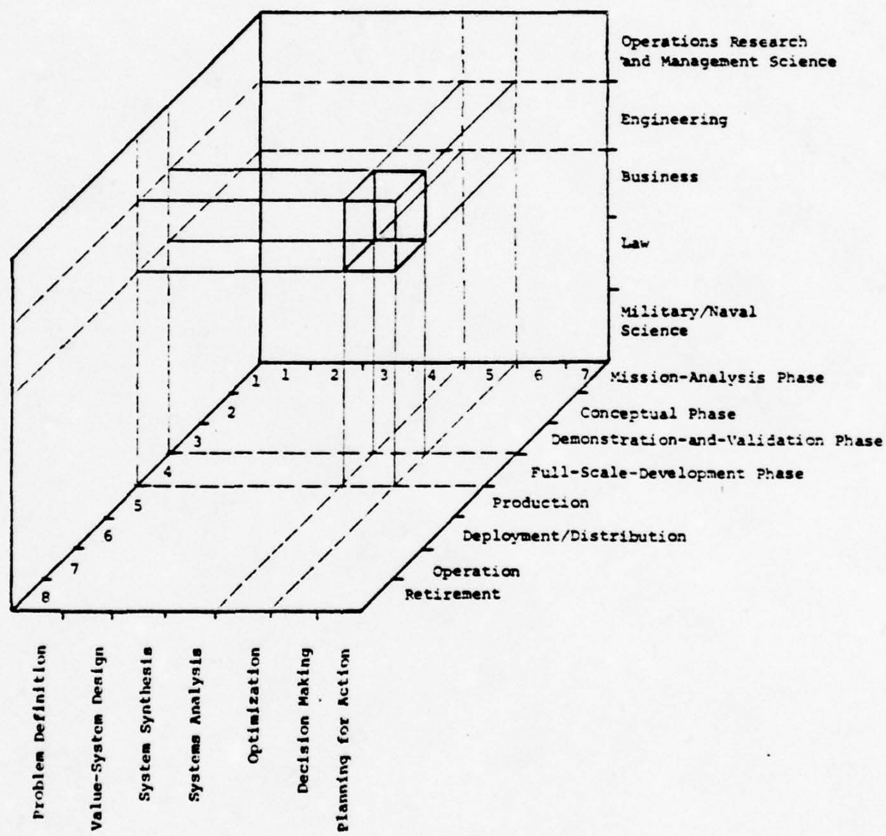

Figure 13. The Morphological Box for Systems Engineering Adapted for Systems Acquisitions (after Hall, 1969).

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Chapter 4

THE DEVELOPMENT OF THE SYSTEMS-ENGINEERING METHODOLOGY FOR APPLICATION TO THE SYSTEMS-ACQUISITION PROCESS OF THE DEPARTMENT OF DEFENSE

Introduction

During the past several years, the procurement policies of the federal government have come under close scrutiny from many sources. In the early 1970's, the Commission on Government Procurement studied these policies and issued a report that documented a number of recommendations. These recommendations evolved into the revised procurement policies presented in the OMB circular, *Major Systems Acquisition, A-109* (OMB, 1976a), issued by the Office of Federal Procurement Policy (OFPP) on April 5, 1976.

This circular defined a major system as, "that combination of elements that will function together to produce the capabilities required to fulfill a mission need." Major programs were defined as those that "are directed at and critical to fulfilling an agency mission, entail the allocation of large resources, and warrant special management attention." OMB Circular A-109 also established key systems-acquisitions policies by requiring that:

1. *Program management be strengthened.* A program manager must be designated with complete authority and responsibility for the systems-acquisition effort as soon

as a need has been approved by the agency head. A program manager must understand the user's needs and constraints, be familiar with development principles, and possess the requisite management skills and experience.

2. *Congress be informed of a new need process.* As soon as a new mission need has been approved by an agency head and authorization has been given to explore alternatives, Congress should be informed. Congress must be able to consider a need on its merits early in the acquisition process before major resources have been committed and a systems problem has been resolved. This early notification enables Congress to continuously compare the needs of all agencies and their associated acquisition programs.

3. *An acquisition executive be designated.* "The head of each agency that acquires major systems will designate an executive to integrate and unify the management process for the agency's major systems acquisitions and to monitor implementation of the policies and practices set forth in the Circular" (OMB, 1976a).

4. *A need be expressed in mission terms.* An agency's needs are the capabilities required to successfully carry out its overall mission. The need for a new major system must be expressed in mission terms, not defined in equipment terms, so that Congress and the agency head can meaningfully trade-off needs after considering the overall capabilities, resources, and priorties.

5. *Alternative systems be explored.* Alternative systems-design concepts must be explored within the context of the agency's mission need and program objectives and innovative and conceptual competition must be actively generated from industry. Alternatives should be formally solicited without bias from industry and other sources based on mission and functional specifications. The *best* possible design should be sought by thoroughly exploring alternative systems-design concepts and tradeoffs of capability for schedule or cost.

6. *The four major program decisions be reserved for the agency head.* The right to make four major milestone decisions must be reserved for the agency head. These milestones are the go/no-go decisions that require the reaffirmation of a prior decision and determine whether or not the system development will proceed into the next phase. By making these key decisions, the agency head controls the various systems acquisitions within the agency while considering the cost and other limitations of the agency's capabilities and resources. The four key decisions that the agency head must make are: (1) approval of a newly defined need, (2) selection of competitive design concepts to be advanced to the test and demonstration phase, (3) commitment of a system to full-scale development, and (4) commitment of the system to full production.

The overall systems-acquisition process as envisioned by the OMB circular was detailed in the OFPP's Pamphlet No. 1 (OMB, 1976b). The process begins on the left of the DELTA chart of Figure 14 with a continuing mission-area analysis by the agency. When this analysis identifies a deficiency in an existing agency capability or an opportunity is identified for a technological improvement that will establish a new capability, the deficiency is formally documented in a mission-need statement. This mission-need statement fully defines the purpose, projected capability, agency components, constraints, value, and priority of the need. As shown in the DELTA chart, the mission-need statement is then submitted to the agency head for approval. This action represents Milestone 0 of the process.

The approval of a mission need starts the major systems-acquisition process by authorizing the agency to explore alternative-design concepts. A program manager is then designated who, with a staff, develops an acquisition strategy. The acquisition strategy is an overall approach or plan to meet the program objective in an economic, effective, and efficient manner. Solicitations are then sent to the appropriate industry requesting proposals for alternative systems designed to satisfy the approved mission need. After proposals are evaluated, parallel short-term contracts are awarded to further explore and define the alternatives. From these alternatives, selected concepts are recommended for

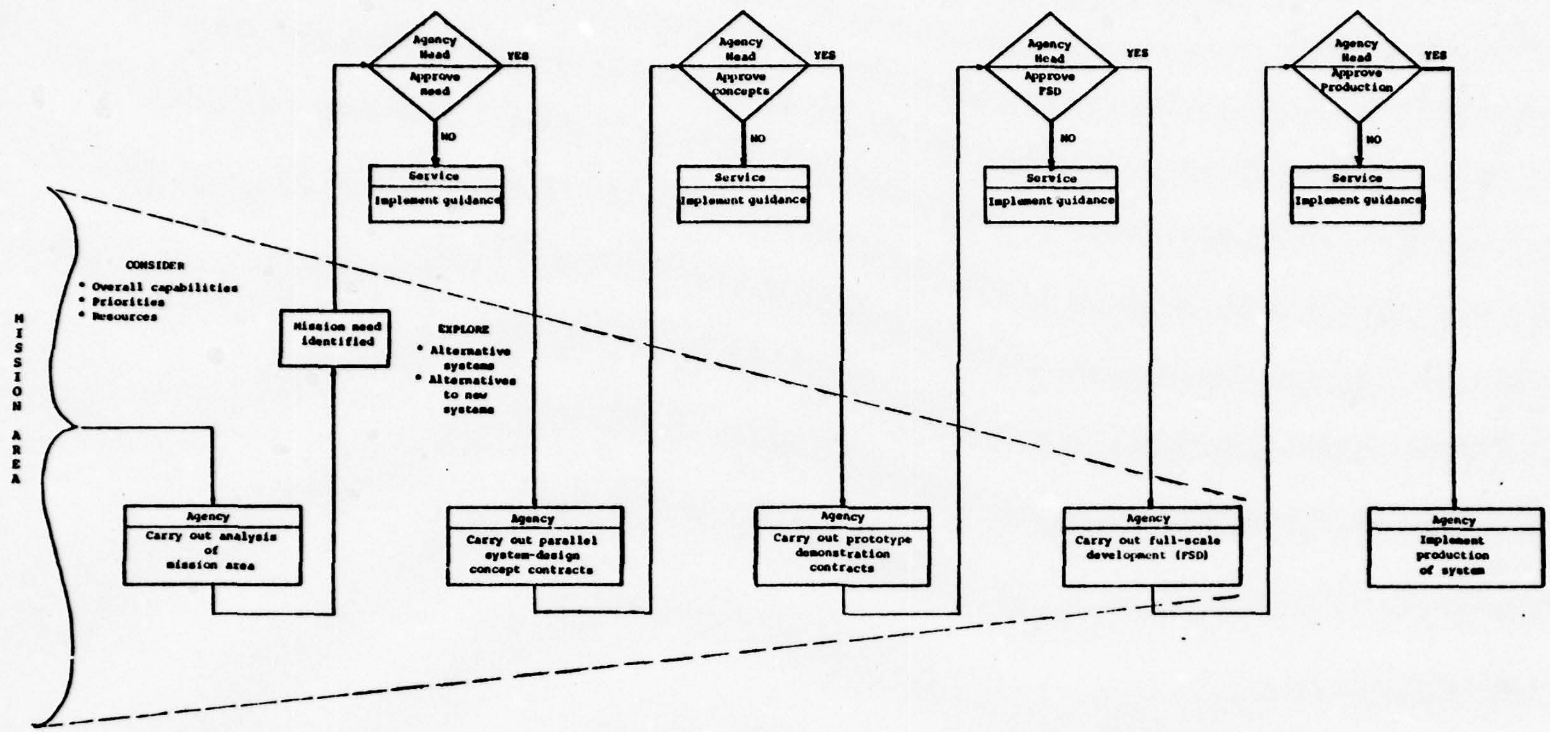

Figure 14. A-109 (OMB, 1976), Major Systems-Acquisition Process. This chart represents an overview of the systems-acquisition process assuming approval of the program at the decision points and a normal progression towards production. Each phase between the decisions could have a feedback loop to provide for iteration of the analysis effort (see Figs. 9, 10, 11, 12).

demonstration. The consideration of these alternative concepts and the approval by the agency head to enter the competitive-demonstration phase of the acquisition process is Milestone I (Figure 14).

Competitive-demonstration contracts are then awarded. These demonstrations should verify that the selected design concepts are sound, assure that they perform in an operational environment, and provide sufficient data to evaluate and select the systems-design concepts to be continued into full-scale development. The decision by the agency head to proceed to full-scale development is Milestone II on the DELTA chart.

Full-scale development is then carried out. Following satisfactory test-and-evaluation results and reconfirmation of the mission need and program objectives, the agency head can authorize full production. This is Milestone III (Figure 14).

The broken lines of Figure 14 represent the progressive narrowing of viable alternatives (as a function of development time) to be chosen as the solution for an established need. These broken lines also illustrate the progressive minimization of participating contractors throughout the acquisition process.

The Department of Defense (DOD) has directed the implementation of the policies in *Major Systems Acquisition* (OMB, 1976a) through two revised directives, *Major Systems*

Acquisitions (Defense, 1977a) and *Major Systems Acquisition Process* (Defense, 1977b). The provisions of the first DOD directive 5000.1, defined a major systems-acquisition program as one with projected research, development, test, and evaluation (RDT&E) cost of $75 million or a projected procurement cost of $300 million.

This directive also established the position of Defense Acquisition Executive (DAE) (whose responsibilities are outlined in a further directive [Defense, 1976b] as the focal point in the Office of the Secretary of Defense (OSD) for systems acquisition. In keeping with the policies of the original OMB directive, this DOD directive reserved the following four key major-program decisions for the Secretary of Defense (SECDEF):

1. Milestone 0 - Decision for Program Initiation (Approval of Need)
2. Milestone I - Decision to Proceed to Demonstration and Validation
3. Milestone II - Decision to Proceed to Full-Scale Development
4. Milestone III - Decision for Production and Deployment

Generally, the acquisition policies set forth in this first DOD directive, 5000.1, were consistent with those already mentioned in the OMB circular, A-109. However, 5000.1 also provided additional guidance on establishing advisory councils to make recommendations in the systems-acquisition decision process and on documenting a major systems program.

The establishment of a Defense Systems Acquisition Review Council (DSARC) and (Service) System Acquisition Review Council ([S]SARC) was stipulated in 5000.1. The DSARC was established to review major programs and make recommendations to SECDEF prior to the major decisions at Milestones I, II, and III. The (S)SARC was to perform the same type of function for the Service Secretary (SERVSEC) for the major-decision Milestones I, II, and III before the DSARC, DAE, and SECDEF considered the program.

The Gantt chart of Figure 15 graphically portrays the sequence of the systems-acquisition process. The phases of mission analysis, conceptual (development), demonstration and validation, full-scale development, and production and deployment are shown interspaced with the four major-decision milestones. The chart also shows the sequence of the (S)SARC review, SERVSEC decision, and DSARC review prior to the SECDEF decisions at Milestones I, II, and III.

A Mission Element Need Statement (MENS) and a Decision Coordination Paper (DCP) for each major program are also required by 5000.1. The MENS documents the mission need in terms of the mission-element tasks, the enemy threat, the existing DOD capability to accomplish a mission, and the constraints on a problem. It also establishes a program plan to identify and explore competitive alternative systems.

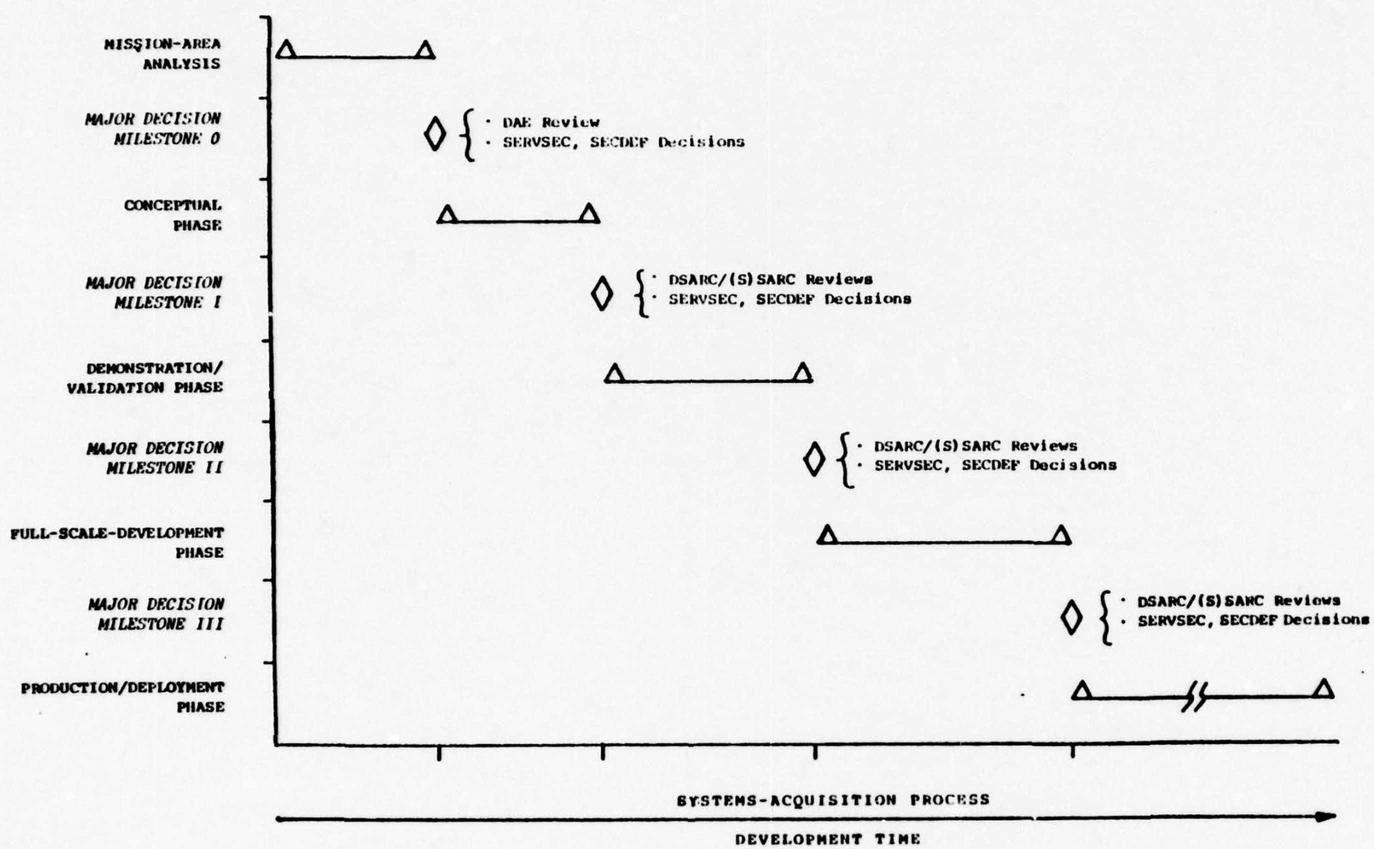

Figure 15. The Sequence of Systems-Acquisition Phases and Decision Points for Major Programs.

The DCP, developed and updated prior to Milestones I, II, and III, consists of an updated MENS, an acquisition strategy, a business plan, a management plan, the areas of program uncertainty, the required resources, a testing and evaluation (T&E) plan and status, the program issues, DSARC and (S)SARC recommendations, and SECDEF decisions and direction. The DCP, as a decision vehicle for the DSARC/(S)SARC, provides the justification and motivation for and the current development status of a program. Directive 5000.2, *Major Systems Acquisition Process* (Defense, 1977b), outlined in more detail the data required for the MENS and for the DCP at Milestones I, II, and III.

The several directives discussed above form a systems-acquisition-policy framework for the DOD. This chapter develops a systems-engineering methodology for systems acquisition within the DOD policy framework using the decision processes leading to the four major-decision milestones. Developing and processing the MENS and DCP through the (S)SARC, SERVSEC, DSARC, and SECDEF are emphasized.

The employment of a systems-engineering approach for R&D projects was discussed by Gibson (1979). The need for a meaningful project analysis to evaluate alternatives for a development program was outlined by Werber (1973). Moore (1975) argued that both the costs and benefits of projects must be quantitatively considered when designing an overall research program. The measurable effects of using systems

engineering in planning and controlling various government R&D projects were covered by Gerloff (1973). Hovanessian (1975) stated the desirability of applying systems-engineering methods to the development of large-scale, military electronics systems. These several references assisted in guiding the development of a systems-engineering approach to be applied to the major-decision milestones.

This chapter sets forth the existing decision-process procedures, identifies the value-system operation, and describes the nature and structure of the process. This chapter also identifies the criteria and organizational considerations for applying the systems-engineering tools and techniques within a methodology. The areas of a systems-acquisition decision process where the application of systems-engineering might pay the greatest return are identified. An appropriate systems-engineering approach is developed by selecting the analysis procedures and associating them with the decision-process support areas. Finally, the developed systems-engineering approach is applied to an existing DOD systems acquisition.

The material in this chapter was developed from several sources. The referenced technical papers and Defense documents established a foundation. This foundation was built upon with the information gained through personal discussions with the people listed in Appendix B, who are associated with Defense systems acquisition. The information gained from these discussions

was supplemented by data from a number of working papers provided by the same people. Finally, the author's four-years experience in Defense R&D provided a background for the research.

The sources noted above were used to develop a mosaic of the Defense systems-acquisition process. The material presented in *Existing Procedures and Value System* (p.127) and *The Nature and Structure of the Defense Systems-Acquisition Process* (p.144) is a descriptive senario of how the process actually works. However, despite the validation of the material through many discussions with DOD systems-acquisition personnel, the final results are from the author's perspective. A description of the process could not be universally accepted by all parties associated with Defense systems acquisition.

Although the descriptive scenario is important, the major goal is to develop a methodology for Defense systems acquisition. A normative scenario of how the process should operate is presented in *Development of Systems-Engineering Methodology* (p.183) and *Implementation of the Methodology* (p.237).

Existing Procedures and Value System

The two DOD directives, 5000.1 and 5000.2, established the basic DOD policies for systems acquisition. However, a number of other directives also set forth DOD policies directly related to the systems-acquisition process. Included in these other directives were:

1. *Defense Acquisition Executive*, DOD Directive 5000.30 (Defense, 1976), outlined the responsibilities of the DAE;

2. *Planning, Programming and Budgeting Systems*, DOD Directive 7045.7 (Defense, 1969), set forth the policies for planning, programming, and budgeting system (PPBS);

3. *Test and Evaluation*, DOD Directive 5000.3 (Defense, 1978d), which established the policies for T&E in the acquisition of Defense systems;

4. *Design to Cost*, DOD Directive 5000.28 (Defense, 1976c), established the policies for the application of design-to-cost principles;

5. *Cost Analysis Improvement Group*, DOD Directive 5000.4 (Defense, 1976a), which outlined the policies of the cost-analysis improvement group (CAIG) in relation to independent cost estimates for systems under development.

Each service headquarters implemented the policies of DOD Directives 5000.1 and 5000.2 by issuing its own policy directive. The variety of approaches the several services have used to implement the DOD directives is shown in the policy documents that each has issued. For instance, the Air Force has recently issued *Statement of Operational Need*, AFR 57-1 (USAF, 1978), which outlined in great detail the Air Force's policies for developing and processing the MENS; other services have not addressed this issue in such detail.

The individual services' systems-acquisition policies and related documentation have also varied in the procedures associated with the DSARC/(S)SARC. The Army issued *Systems Acquisition Review Council Procedures*, AR 15-14 (Army, 1978b), which provided detailed guidance governing the operation of

the Army Systems Acquisition Review Council (ASARC) and the Army's involvement in the DSARC. These policies were further amplified by an Army directive from the Office of the Deputy Chief of Staff for Research, Development, and Acquistion (ODCSRDA), *ASARC/DSARC Procedures*, Regulation 15-14 (Army, 1978a), which provided detailed procedures within the ODCSRDA for the ASARC/DSARC process. The other services have not addressed this subject in such detail.

Justifications for these various approaches are related to how the services viewed their responsibilities and their relationships with OSD and subordinate commands. The arguments for these approaches are not of interest here, but differences do exist, not only in policies but also in procedures.

The nature of the programs subject to review through the DSARC/(S)SARC process also differ. First, there are the functional differences of the mission-area needs, such as, the development of the FFG-7 Guided Missile Frigate required for surface-warfare missions, the F-16 Fighter required for tactical-air missions, or a new main battle tank required for close-combat (ground forces) missions. Second, the program could be divided into strategic and tactical programs. Strategic programs could cause management problems because the data associated with the programs were limited by security restrictions. Third, the programs could be divided into new development programs, as was the Missile X (MX) program, or modification programs, as was the

Air Force's cargo-plane modification C-141 (the Stretch program). Other classification systems could also be devised.

The differences noted above are significant to the services' management approaches and to the programs themselves. However, the management approaches of the services and the way the various programs are addressed are fairly consistent because of the parent DOD directives, 5000.1 and 5000.2. In particular, the MENS with its approval cycle and the DCP with the (S)SARC/SERVSEC and DSARC/SECDEF approval cycle unify the overall Defense systems-acquisition process. These requirements have encouraged consistency in the overall process and provided substantative activities about which the systems-engineering approach can be developed.

The overall procedure for developing, processing, and approving the MENS is graphically portrayed in the DELTA chart of Figure 16. The procedure begins with a continuing mission-area analysis by the service. Based on this analysis, a new mission-element need is identified. This need is documented in a draft MENS by the requirements command of the service. The draft MENS is then reviewed by the service headquarters and either approved or disapproved by the Service Secretary. The draft MENS is revised as deemed appropriate by the several review authorities and then forwarded to OSD for review by the OSD staff and the DAE. After this review, the draft MENS is either approved or disapproved by the SECDEF. If the draft MENS is approved, appropriate actions are taken

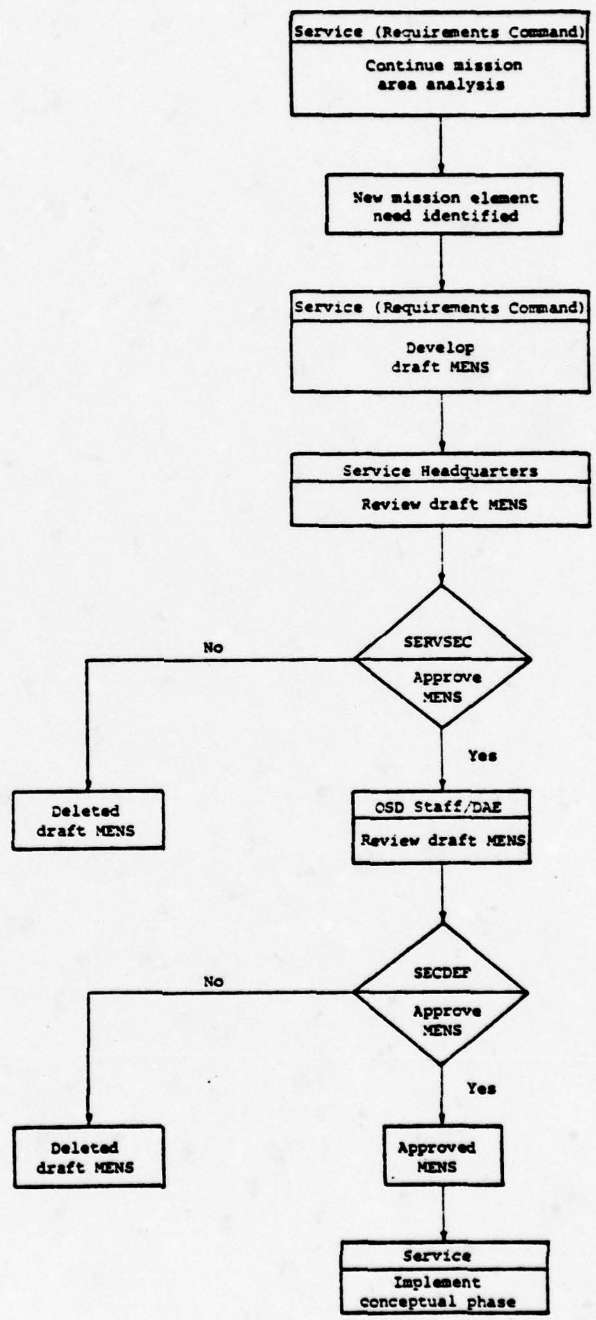

Figure 16. MENS Development, Processing, and Approval.

to update the PPBS. This update will insure that the PPBS (including the Program Objectives Memorandum [POM] and Five Year Defense Plan [FYDP]) is in consonance with the systems-acquisition plans. Finally, the program-management charter is issued establishing the program-management office.

The overall cycle for the development, processing, and approval of the DCP is graphically portrayed in the DELTA chart of Figure 17. The cycle begins with the SECDEF's decision that ends the previous phase and begins the new phase. This decision is documented in the DCP and results in an update to the PPBS and the program-management directive for the systems-program office. The systems-program office then carries out the next phase of the systems-acquisition process culminating in the recommendations for the next phase. These recommendations are provided to the service headquarters, which develops a draft DCP. The chart also indicates that independent program assessments may be carried out external to the headquarters.

The draft DCP and the critical issues associated with the program are next reviewed by (S)SARC and recommendations are made to the SERVSEC. Appropriate action is then taken on the DCP by the SERVSEC. If the SERVSEC approves the draft DCP, it is then forwarded to the DAE and OSD staff for review. The CAIG carries out independent cost estimates; other OSD staffs can also conduct independent program evaluations. The DSARC reviews the DCP and the critical issues associated

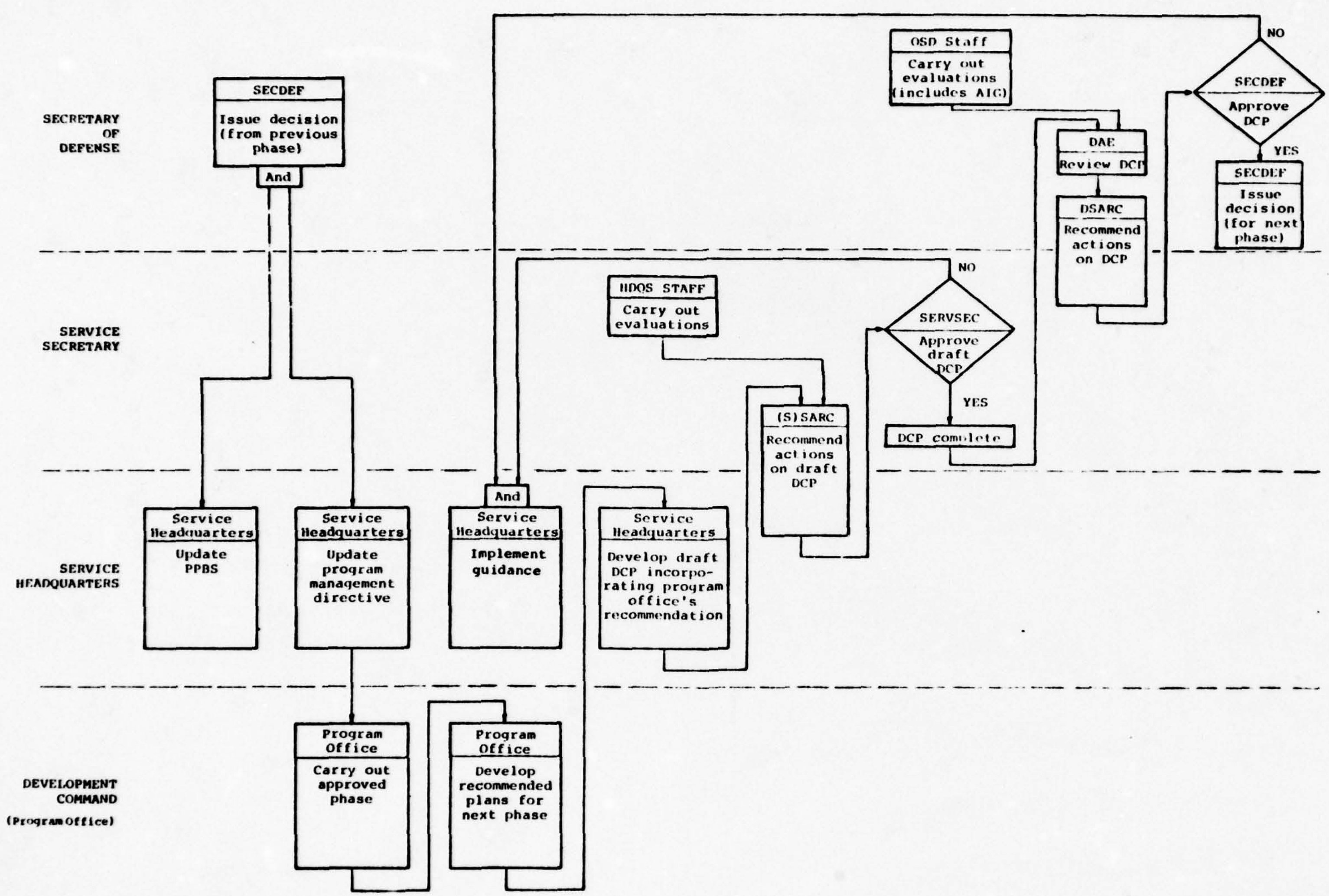

Figure 17. Decision Coordinating Paper (DCP) Approval Cycle, including Independent Evaluations.

with the program and makes recommendations to the SECDEF. Finally, the SECDEF takes action on the DCP and issues his decision thus completing the cycle.

The membership of the DSARC and the (S)SARC is important for an understanding of the overall DOD systems-acquisition decision process. Comments on the membership of the several councils are presented below.

The members of the DSARC are senior civilian managers from OSD, including the DAE (Chairman)/Under Secretary of Defense for Research and Engineering, Assistant Secretary of Defense (Comptroller), Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics), Assistant Secretary of Defense (International Security Affairs), Assistant Secretary of Defense (Program Analysis and Evaluation), and the Special Advisor for NATO Affairs. Usually, these individuals have had previous executive experience in government, industry, or commerce and hold a graduate degree (or its equivalent) in a discipline associated with the particular position. For instance, the Under Secretary of Defense for Research and Engineering has traditionally held a doctorate of science.

The membership of the individual (S)SARC is somewhat more heterogeneous than the membership of the DSARC. The Marine Corps Council is almost exclusively general officers (Navy, 1979), the Army's council is predominately general officers but also has several senior, civilian service secretaries (Army, 1978a), and the Air Force (USAF, 1977) and

the Department of the Navy (Navy, 1978) have about equal representation of generals or flag officers and senior, civilian service secretaries as members on their councils. Many of these individuals hold graduate degrees but not necessarily in a discipline closely associated with their current position. The majority of these officers have previously attended a top-level military school; such as, the National War College, Industrial College of the Armed Forces, the Army War College, or the Naval War College. Normally the service secretaries have previous executive experience and the officers have spent many years in both operational and staff positions.

In studying the decision process of Defense systems acquisition, the value system of the DOD (and specifically the DSARC) must be considered--what are the goals of systems acquisition that the DOD seeks to obtain. The motives and intentions of the DSARC members and consequently the systems-acquisitions questions they must answer are influenced by these goals and by the background, experience, education, and position of each member.

The attainment of these goals is limited by the following considerations: the available resources (qualified DOD personnel, funds, qualified contractors, facilities, etc.), the management time available, the political environment in the federal government, and the existing systems-acquisition policies. The alterables to be considered for this problem

are the management information provided to the DSARC, the analysis approaches used to address the problems, the OSD-established procedures for preparing and executing the DSARC, and the policies associated with the overall process. Similar sets of constraints and alterables exist for the (S)SARCs. The means by which the achievement of a goal can be measured is discussed in *Implementation of the Methodology* (p.237).

At the top-most level of objectives, the DOD may simply be considered an instrument to pursue national policies. The acquisition of Defense systems can be viewed as supporting this objective since the systems-acquisition process provides the capabilities to implement the policies. President Carter addressed such a top-level goal at the NATO summit meeting in London in May of 1977, when he stated,

> We must combine, coordinate, and concert our national programs more effectively. We must find better ways to bring new technology into our armed forces. We must give higher priority to increasing the readiness of these forces. (Freeman, 1978)

DSARC members review the costs and benefits of various acquisition programs while attempting to achieve several objectives. They must be responsive to the lead of Congress and to the guidance of the DOD in systems-acquisition matters. They need to be concerned with the maintenance of a viable Defense industry in the United States (Gansler, 1977) and with a strong systems-acquisition management capability in the services (Packard, 1971). International security matters

must also be considered. An example is the expressed concern of Dr. William J. Perry, then Under Secretary of Defense for Research and Engineering, for the Russian capability to destroy incoming cruise missiles (Klass, 1978).

In attempting to develop the best overall program of systems acquisitions, the DSARC members are affected by their OSD staff positions and their own personal-preference goals. The objectives being sought by the members include the achievement of NATO interoperability and standardization (Freeman, 1978), the documentation of the MENS for various acquisition programs (Defense, 1978b) and the identification of critical issues and evaluation criteria for each program.

Several recommendations were presented in the Defense Science Board Task Force Report (Defense, 1978c) on systems acquisitions. The objectives based on this report are: to minimize the length of the development cycle for acquisition and to improve the initiation of the process, to establish a minimum set of programs necessary to meet national defense requirements, and to make systems-acquisition processes more flexible.

The objectives appropriate for consideration by the DSARC members have been formed into an objectives tree (Figure 18). The objectives at each level of this tree contribute to the accomplishment of the objective on the next higher level. The objectives become more specific and concrete as one moves down the tree.

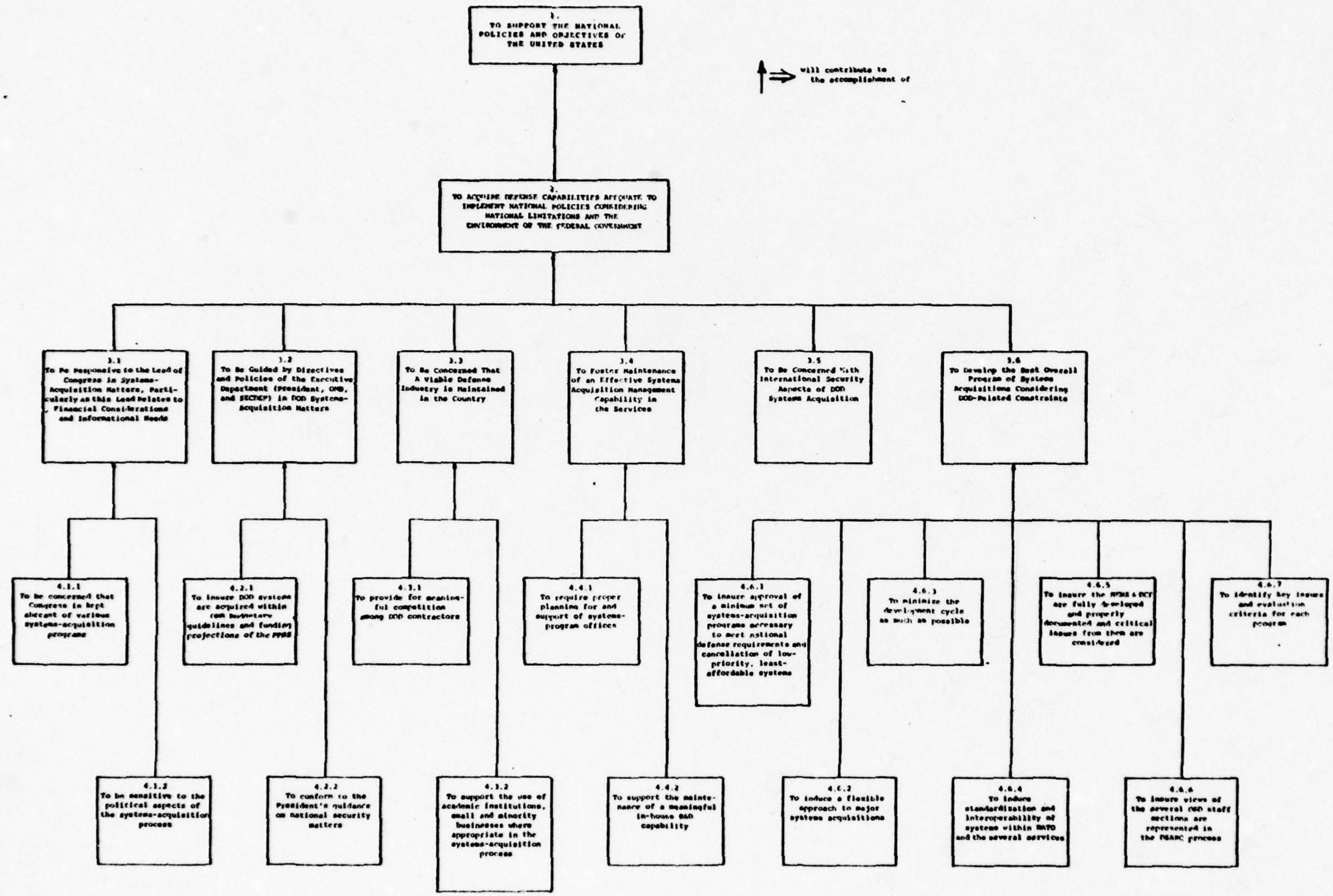

Figure 18. Objectives Tree for the Value System Operating in the DSARC.

A similar objectives tree could be developed for the members of the (S)SARCs. The objectives tree for the DSARC and the one for the (S)SARCs would be quite similar; most changes would simply reflect the services' subordination to the SECDEF. However, there would be one significant difference in the (S)SARC objectives tree because the members of the (S)SARC are motivated by the institutional values of their respective services. They are concerned with the survival of their service and the perpetuation of the traditional roles and missions of their service, which is reflected in their wish to obtain systems that support these missions. (For instance, the pursuit of the development program for main battle tanks by the Army and tactical aricraft by the Air Force.) An objective on the 3.--level and its subordinate objectives should incorporate this institutional advocacy into the (S)SARC objectives tree.

The objectives for the DSARC and (S)SARCs and the DOD activities associated with them are functionally related in such a way that inclusion in a simple objectives-tree format might be considered inappropriate. For instance, several feedback and feed-forward loops might be identified between the objectives presented in Figure 18. However, the purpose here is to present the goals of the DSARC and (S)SARC members in the most straight-forward manner possible; therefore the objectives tree was chosen as the best approach to display the goals.

The procedures by which the services prepare for their own (S)SARC and the DSARC are also of interest in this study. In reviewing the relevant directives and in discussions with the personnel involved, a great deal of variance was observed in the approaches taken by the services to these preparations. The Army's approach is well documented, highly structured, and apparently closely adhered to. The other services are somewhat less formal in their approach.

A detailed procedural model for the preparations for and execution of the DSARC/(S)SARC(s) that would be applicable to all services cannot be developed. However, a generalized set of procedures, not necessarily in sequence, for these preparations are presented as follows:

1. Program alternatives with the supporting documents are developed and critical issues are identified within the program office.

2. Personnel at commands subordinate to the service headquarters are briefed on the alternatives.

3. Preparations for the (S)SARC are coordinated at the service headquarters.

4. Additional program information is obtained from other commands within the serivce (i.e., T&E data from the test command.

5. A variety of independent analyses are carried out by service headquarters.

6. Prebriefings are held for the principals of the (S)SARC.

7. The DCP is developed or updated at the service headquarters and the (S)SARC is scheduled.

8. The (S)SARC is held; the program manager makes a formal presentation of the mission-element need, program status, critical issues, and projected altérnatives for the next phase; and a specific alternative is recommended.

9. The (S)SARC members make a recommendation that is forwarded, with the draft DCP, to the Service Secretary for a decision.

10. The SERVSEC decides on the critical issues; if the program is approved for continuance, and the draft DCP is then forwarded to OSD with the SERVEC's recommendation.

11. A CAIG independent cost estimate and any other required independent evaluations are submitted.

12. The SERVSEC's decision, the draft DCP, and the supporting documents are reviewed by the DAE and OSD staff.

13. A pre-DSARC meeting with the DSARC principals is held on the specific program.

14. The DSARC is then convened and the program manager makes a formal presentation of the mission-element need(s), program status, critical issues, and projected alternatives for the next phase. A specific recommendation is made as to which alternative should be chosen.

15. The DSARC members make a recommendation that is forwarded, with the draft DCP, to the SECDEF for a decision.

16. The SECDEF decides on the critical issues; if the program is approved for continuance, the final version of the DCP is returned to the service headquarters for implementation of the next phase.

Although the program manager usually makes the formal presentation at the reviews, others may assist. (For example, the Army requires that representatives from its Training and Doctrine Command [TRADOC], The Army's *user*, present the briefing of the MENS, threat assessment, and operational concept.) The time allowed for the overall presentation is usually limited to prevent the briefings from being too lengthy and the technical content is kept to a minimum.

A set of viable alternatives are usually presented to the DSARC or (S)SARC. The program manager should present the key factors of each alternative and recommend a specific one. Although there may be an obvious preferred alternative, the other alternatives should be feasible and capable of being implemented; presenting a very strong recommended solution and very weak alternatives is inappropriate.

The DSARC/(S)SARC members may choose an alternative in a variety of ways. The members may actually vote on a set of alternatives or they may be polled to determine if they are

dissatisfied with the recommended alternative. The members may present dissenting or minor opinions as part of the decision forwarded to the SERVSEC or the SECDEF. Although unusual, because of the political environment within DOD, the Chairman could simply direct a decision. The rules used to arrive at a particular decision (recommendations to the SERVSEC or SECDEF) differ with each council and each program. However, this decision process is a group-decision process in the context of decision analysis (see Raiffa, 1968). The topic of decision analysis is addressed again later in this chapter.

Two final areas are important to the overall decision process--the changing nature of the alternatives and the evolution of a decision process within the service headquarters and OSD. When a particular alternative is first identified, it does not have any particular status. But, as it becomes more clearly defined and identifiable, it tends to gain a life of its own. Advocates come forward from a variety of areas, industry, users, and developers, to support the alternative. After analysis and evaluation, a single alternative becomes the *recommended alternative* at the program-office level. The alternative may then be supported at one or more higher levels. (For instance, Air Force Systems Command normally reviews a program before it briefs the Air Force Headquarters.) The recommended alternative has picked up support from several more echelons of command.

Ultimately the (S)SARC is briefed on the alternatives, a single alternative is recommended to the SERVSEC, and a recommended alternative is forwarded to OSD for review and consideration by the DSARC. At this stage, the recommended alternative is no longer simply a program-office recommendation; rather, it has often taken on the status of a service position--the result of a service assuming the role of sponsor and advocate for the recommended alternative. An approach of this type could, unless carefully controlled, minimize other viable alternatives.

The final comments here concern the evolution of the decision process for systems acquisitions within the DOD. First, the SERVSECs and the SECDEF can and do revise the recommendations of the (S)SARCs and DSARC. Second, several decisions have been well on the way to being completed prior to the (S)SARC or DSARC proceedings because of activities outside the DOD--Congressional action, executive-department decisions, or some other reason. Third, DOD systems-acquisition decisions are not confined to the DSARC/(S)SARCs. Although the DOD policy directives for systems acquisition imply that the DSARC/(S)SARC process works almost unilaterally on systems acquisition, this is not the case. A number of working groups, committees, and councils within the several services have a great affect on the systems-acquisition process, particularly in funding; such as, the development of the POM and FYDP, as each service carries out its PPBS

responsibilities. The Chief of Staff's Committees within the Marine Corps and the Air Council within the Air Force are examples. These top-level review groups are staffed by senior general officers and significantly influence many decisions, including those involving funding and operations.

The DSARC/(S)SARC process is not the single path through which systems-acquisition decisions are made. In some cases the DSARC/(S)SARC process becomes a validation process for decisions that basically have already been made. However, the policies of the DOD and the several services do point toward the DSARC/(S)SARC process as the principal means by which systems-acquisition programs are reviewed and the recommended decisions are developed for the SERVSECs and SECDEF. Also, personnel involved with the systems-acquisition process within the DOD want to make the DSARC/(S)SARC process as viable and meaningful as possible for the various stakeholders of the process, including the services, the executive branch, Congress, the Defense industries, and the American people.

The Nature and Structure of the Defense Systems-Acquisition Process

The projected benefits from implementing OMB circular A-109, *Major Systems Acquisition*, and the two revised DOD directives *Major Systems Acquisition*, 5000.1, and *Major Systems Acquisition Process*, 5000.2, are presented in an article

by Mr. P. R. Calaway, Assistant for Program Planning in the Office of the Under Secretary of Defense for Research and Engineering (Calaway, 1978). Calaway stated, in part,

> A-109 is here to stay. We agree with its principles, and we support it. Why? Because we think it makes sense, and because we think it has the potential to help us shorten the acquisition cycle and get us more capability for our dollar.

These comments gave a rather positive view of the new systems-acquisition policies. However, the implementation of A-109 has not been carried out without problems. The Under Secretary of Defense for Research and Engineering covered some of these problems in a memorandum to senior DOD personnel (Defense, 1978b). The memorandum stated that the DOD had failed to offer Congress the opportunity to debate key mission needs before resources were committed to the identification of solutions, that there was concern about the intent of the MENS in the systems-acquisition process, that what constitutes a MENS was unclear, and that which of the programs required a MENS was confusing. Secretary Perry addressed each issue and set forth additional policies in the memorandum to clarify the requirements of the OMB and 5000.1 directives.

Secretary Perry did not address the root causes of problems in his memorandum. However, these problems were probably caused by an institutional inertia to address systems-acquisition problems in the traditional way, the failure to

penetrate the DOD bureacracy with new procedures, and an honest misunderstanding as to what was desired from the services.

It is appropriate to note the magnitude of the problem of developing MENS for each of the major systems-acquisition programs. First there are many indications that the services view the development of each MENS as a major effort because of a lack of experience and a lack of understanding of what OSD needs and wants. Second, although fifty-seven major systems-acquisition programs required DSARC consideration as of November, 1978 (Defense, 1979), only five MENS had been approved at the OSD level by April, 1979. This observation of MENS(s) was made almost three years after the OMB circular was issued and over two years after the original DOD directives were revised.

During 1977-78, the Defense Science Board Task Force studied the implementation of the systems-acquisition policies in the OMB circular (Defense, 1978c). This task force included members from industry, the OSD, and the military services. Their report was written at the request of the Under Secretary of Defense Research and Engineering and included the following findings and conclusions:

1. *No Sense of Urgency.*

> It takes longer to get things done in the DOD (and elsewhere in the U.S.) than it used to. The increased delays seem to be in the decision process rather than in the time to do the actual work.

2. *Flexibility.*

> The most prominent single thread that was evident throughout all of the data examined by the Task Force was the necessity for and absence of a high degree of flexibility in every application of the policies and practices for acquisition management.

3. *Motivation.* The task force perceived that

> both institutional and personal values have a substantial influence on the acquisition process.

4. *Program Advocacy.* The Task Force noted that there was a high correlation between the programs that had strong advocacy and the programs that were continued in the development cycle. The programs that survived had active and vocal advocates in the sponsoring service, in OSD, in Congress, or elsewhere.

5. *Concurrency.* The task force defined concurrency as

> the conduct of the steps leading to production for inventory before the end of the full-scale development time span.

The task force found that a certain amount of concurrency in a program could shorten the acquisition process and provide a savings over the total acquisition process. This finding was based on the task forces' conclusion that

> a commitment to enter full-scale development should be recognized and accepted as a clear reaffirmation of intent to produce and deploy the developed article, barring truly unforeseen events.

The task force further concluded that the decision for full-scale development (Milestone II) was second in importance only to the Milestone 0 decision, approval of MENS (with intent to produce and deploy).

6. *Prototypes.* The task force also investigated the use of preproduction prototypes before stating that

> prototyping can be a sound and useful practice in major systems acquisition provided that the candidates for the use of prototypes are carefully selected, that only those things are prototyped which really need verification, and that prototypes are not considered to be some form of *free lunch* for the procuring agency.

7. *Operational Test and Evaulation.* The task force identified a flexible testing philosophy as a prerequisite to improving the acquisition process. The desirability of joint testing but independent evaluation and the need for close cooperation between the users and the developers was also discussed.

8. *Early Deployment.* The task force concluded that

> there is considerable evidence to support the claim that early deployment is frequently a useful and valuable practice, particularly in those cases where less than the ultimate system performance is acceptable in the initially-deployed units.

The task force also concluded that early deployment could save significant program costs in terms of reduced inflation, fewer engineering change proposals for *gold-plating*, and a minimization of overhead costs.

9. *The External Environment.* The task force further concluded that

> due to the influence of external forces, the longer a program stays in full-scale development, the greater are its chances of being cancelled prior to completion.

This was caused by personnel and viewpoint changes, DOD, the Congress, the Executive Branch, and the public sector. These changes result in a shift of the priorities, attitudes, and

appreciation of the enemy threat that caused the program to be approved for development in the first place. The recent cancellation of the B-1 bomber program is an example of this phenomenon.

10. *Increasing Realism in Cost Estimation.* The task force concluded that many considerations were important in planning program costs, including allowances for additional tasks, a need for all concerned to *help get the job done*, the selection of sources based on the optimism of contractors rather than realism, and the impact of inflation on lengthy programs.

Based on the above, the task force recommended several acquisition-policy initiatives. These initiatives are reflected in the DSARC/(S)SARC objectives trees (see Figure 18) and are presented below:

1. *Reduce the Number of Programs.* It was recommended,

> That the number of major weapon-systems-development programs should be reduced so that those which are continued are the ones which DOD intends to--and can afford to--put into production and deployment.

2. *Demand and Approve a Flexible Approach.* The task force recommended a flexible approach to the systems-acquisition process that would include a broad, generalized approach at the policy level, basing competitive selections on achievement; the careful development of the MENS to enable a variety of alternatives to respond to it; the use of the DSARC for decisions and program reviews; and the adjustment of thresholds for programming funds.

3. *Improve and Shorten the Front End of the Cycle.* The task force also recommended that

> the formal steps in the definition and approval of an acquisition program be reduced wherever appropriate to the needs of the individual program, either by complete elimination of certain steps or by their combination with other milestones.

The comments with this recommendation indicated that recent policy changes have elongated rather than shortened the mission-analysis (program initiation and definition) phase.

The Defense Science Board Task Force's recommendations were reviewed by the DEPSECDEF after which he recommended that his subordinates in the DOD study the report for possible implementation of the recommendations (Defense, 1978a). The DEPSECDEF directed special attention to the recommendation "to improve the acquisition process by reducing the length and cost of the cycle from initial conception to operational deployment."

Industry, too, has been concerned about the implementation of OMB A-109. One of industry's principal spokesmen, Mr. John H. Richardson, President of Hughes Aircraft Company, has demonstrated a continuing interest in Defense systems-acquisition as indicated by his comments in *Government Executive* (December, 1974; February, 1976), his position on the Board of Visitors of the Defense Systems Management College, and his frequent appearances as a guest speaker at the college. In April, 1978, Richardson testified about OMB A-109 before the Subcommittee on Research and Development, Committee on

Armed Services, U. S. House of Representatives, on behalf of the Aerospace Industries Association of America, Inc. (Congress, 1978). Initially he pointed out that the aerospace manufacturers strongly supported the thrust and most of the particulars of OMB A-109. However, he also pointed out several potential problems that the industry perceived with the implementation of A-109.

First, he expressed concern that there would not be adequate funding of the competitive Concept Formulation Phase following Milestone 0 and all subsequent phases. If this happened, then industry would have to rely on the Independent Research and Development (IR&D) funds provided by the federal government for creative R&D within the companies. Richardson suggested that this could lead to a significant and dangerous degradation of the technology base.

Second, he was concerned that overspecification of the program would undercut the intent of the OMB circular. He felt that there were too many inhibiting details and specifications in the MENS, the Request for Proposal (RFP), and the contract. These documents could be stumbling blocks to the smooth forward progress of the program.

Third, he stated that OMB A-109 could lengthen the acquisition process rather than shorten it because of the possible systems-acquisition problems identified by the Defense Science Board Task Force Report (1978a). He supported the task force's recommendations for a flexible approach to these problems.

Richardson reiterated these problems in his briefing at the National Conference of the American Insititute of Aeronautics and Astronautics in Los Angeles, California on November 16, 1978. In particular, he spoke of the growth of the projected development time for Defense programs under various acquisition policies over the last twenty years (Figure 19). He projected a possible cycle of sixteen years from approval of the MENS to an initial operational capability (IOC). Richardson argued that the adoption of a flexible system-acquisition approach as recommended by the Defense Science Board Task Force could reduce the acquisition cycle to from six to eight years by the 1980's. Figure 20 contrasts the two approaches.

Thus far in this section the implementation of A-109 has been viewed from several prospectives--that of the Under Secretary of Defense Research and Engineering, the Members of the Defense Science Board Task Force, and a senior representative of industry. From these comments, the following observations of the systems-acquisition process should help to develop an applicable systems-engineering methodology:

1. A mission-element need is identified almost randomly; as a result the draft MENS is processed and evaluated in a serial process rather than in a parallel. Developing the *best* overall DOD systems-acquisition program could be better achieved if the draft MENS(s) were batchprocessed for evaluation.

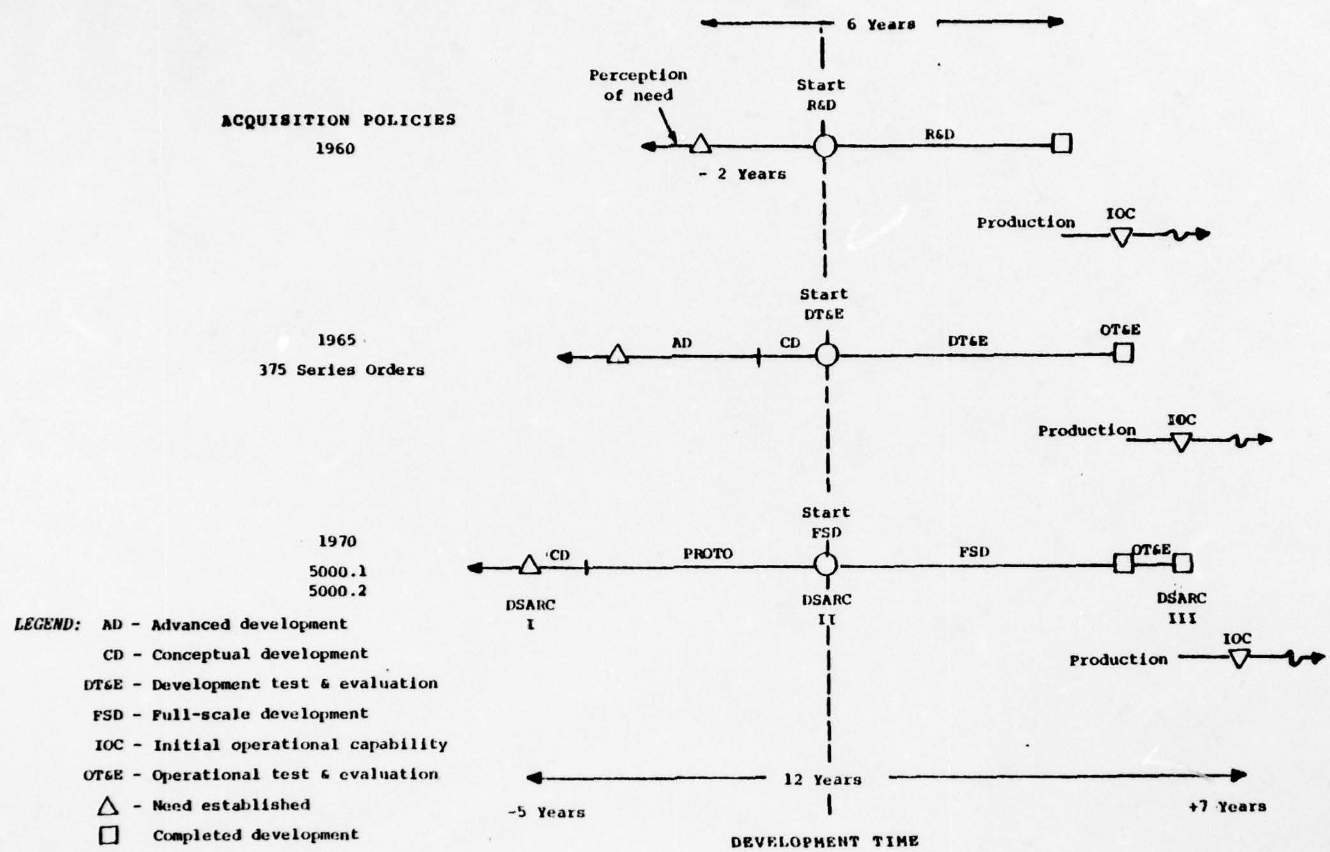

Figure 19. Growth of Projected Development Time for Defense Programs under Various Acquisition Policies (Richardson, 1978).

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A METHODOLOGY FOR DEFENSE SYSTEMS ACQUISITION.(U)

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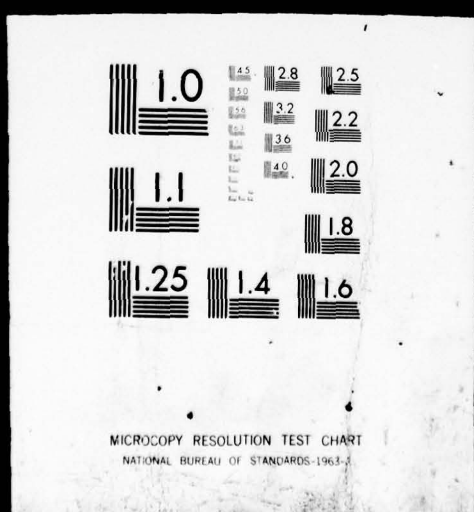

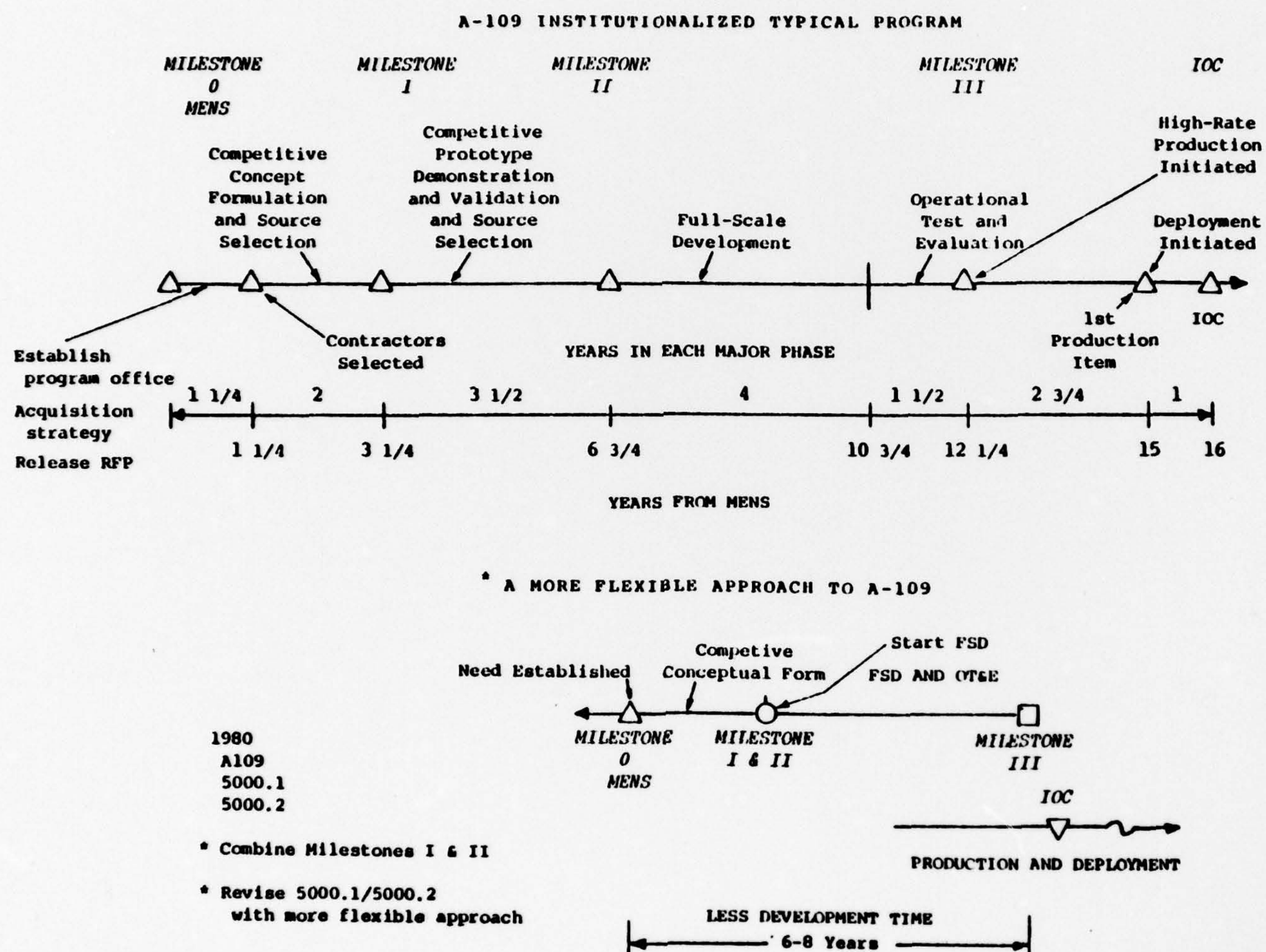

Figure 20. A-109 (OMB, 1976) Institutionalized Typical Program, contrasted with a More Flexible Approach (Richardson, 1978)

2. It is very difficult to trade off any given program against other programs because of the random development of the draft MENS(s) as a function of time.

3. A MENS has not been developed for all programs.

4. All programs should be subjected to (or clearly exempted from) the MENS process to establish a uniformity of policy application and equity in evaluation and selection. Currently there is a feeling that those programs that have undergone the MENS process have suffered some ill-defined penalty to which the other programs have not been subjected.

5. Since the MENS presents the results of the problem-definition phase, it is very critical to the overall cycle.

6. Once the MENS is approved, the program begins a *life* of its own and is very difficult to cancel.

7. Developing a MENS could add an additional front-end to the programs, thereby elongating the acquisition process.

8. The decision options become fewer and fewer as the program moves through the acquisition cycle.

9. It is desirable and beneficial to move the programs through the acquisition process (and hence the major-decision milestones) as speedily as possible, consistent with good judgment.

10. The nature of the decisions required at each major-decision milestone is different:

a. *Milestone 0* (Program Initiation and Advancement to Conceptual Phase). At this point, limited quantative data are available on such items as the threat assessment and the existing capabilities. However, this decision is a go/no-go decision to initiate a program based primarily on its qualitative aspects. When this decision is addressed, nature, structure, and final outcome of the program are questionable. The key questions to be answered are: (1) Is a program required to answer the mission need? (2) Is this program of greater value to the national-defense effort than other available programs or investments? It is very difficult to trade off a specific program against other possible programs because of the time variation of the identification of a mission-element need.

b. *Milestone I* (Approval for Advancement to the Demonstration-and-Validation Phase). More quantative information will be available on the program at this point but uncertainty and the associated risks remain quite high. Critical issues are addressed and alternative candidate solutions are evaluated. The alternatives are traded off among themselves, and several alternatives are selected for continuation into the next phase. This evaluation-and-selection process begins in the program office and culminates with a decision from the SECDEF.

c. *Milestone II* (Approval for Advancement to the Full-Scale Development Phase). The quantative information

begins to dominate the qualitative aspects of the program; uncertainty and its associated risk are reduced. Critical issues are addressed and the alternate solutions are evaluated; the remaining alternate candidates are traded off among themselves. A specific alternative will be selected for full-scale development in much the same way as the Milestone I decision was made. The evaluation-and-selection process will begin in the program office and culminate with the decision of the SECDEF. Because a program should not be permitted to enter full-scale development unless it will probably go to production, this decision is second in importance only to the program-initiation decision.

d. *Milestone III* (Approval for Production and Deployment). At this point reliable quantitative data should be available on almost all aspects of the program. Therefore, program uncertainty and its associated risks should be minimal. This decision is only slightly less critical than the Milestone II decision since it represents a final commitment by the service to produce and deploy the system. Critical issues are considered and the decision is basically a go/no-go decision to produce. No alternative candidate solutions are evaluated or alternatives selected. The recommendation to go or not to go into production begins in the program office and culminates with a decision from the SECDEF.

11. There are several DOD systems-acquisition policy initiatives that should be implemented:

a. That a more flexible approach be adopted for the overall process.

b. That the policies outlined in OMB Circular A-109 be integrated with the programming requirements of PPBS and the Congressional budget cycle.

c. That a MENS, the critical-requirements document for each program, clearly define the problems.

d. That the mission-analysis effort prior to Milestone 0 be clearly identified as a phase of the systems-acquisition process. (This is a service responsibility for requirements determination but also a problem-definition phase in the overall DOD process.)

e. That a procedure be developed to allow for the evaluation and trade off of programs early in the acquisition cycle at the DOD level. (This procedure would allow for the determination of the *best* overall systems-acquisition program for the DOD.)

The overall structure of the systems-acquisition problem should also be investigated. First, the preceding portion of this dissertation, where the systems-engineering morphology was used to model the systems acquisition process, is reviewed. Then, the systems-acquisition process is examined to see its possible relationship to the *Stage Approach* for evaluating and selecting R&D projects as outlined by Albala (1976).

In the previous chapter, the systems-acquisition process was compared to the morphology of systems engineering (see Hall, 1969). This morphology is a framework consisting of three dimensions: time, logic, and knowledge. The time dimension includes the coarse-grain phases that characterize the systems work from the initial conception of a problem through the retirement of a system. The logic dimension deals with the steps or activities that are carried out in each systems-engineering phase. The knowledge dimension refers to the specialized knowledge of the different professions and disciplines required for systems works.

The time-dimension phases from the systems-engineering morphology encompass program planning, project planning, systems development, production, distribution, operation, and retirement. These phases are compared to the Defense systems-acquisition phases as shown in Table 6. The phases of the morphology are closely related to the phases of the systems-acquisition process.

The logic-dimension steps of the systems-engineering morphology consist of problem definition, value-system design, system synthesis, systems analysis and modelling, optimization, decision making, and planning for action. These steps are compared to the activities of the several phases of the systems-acquisition process as shown in Table 7. The activities from each phase correlate favorably with the steps of the logic dimension. Justification for this observation is

TABLE 6

THE TIME-DIMENSION PHASES OF THE SYSTEMS-ENGINEERING MORPHOLOGY COMPARED TO THE PHASES OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Time-Dimension Phases[1]	Systems-Acquisition Life-Cycle Phases
Program planning	Mission analysis and development of MENS
Project planning	Conceptual
	Demonstration and validation
System development	Full-scale development
Production	Production
Distribution	Deployment or phase in
Operation	1. Operation/support 2. Maintenance/repair 3. Modification/retrofit
Retirement	Retirement or phase out

[1]See *The Systems-Engineering Framework* (p. 67).

TABLE 7

COMPARISON OF THE LOGIC-DIMENSION STEPS OF THE SYSTEMS-ENGINEERING MORPHOLOGY WITH THE ACTIVITIES OF THE FOUR PHASES OF THE SYSTEMS-ACQUISITION PROCESS

Systems-Engineering Logic-Dimension Steps[1]	Systems-Acquisition-Phase Activities			
	Mission Analysis	Conceptual	Demonstration and Validation	Full-Scale Development
Problem definition	Mission need identification	Define acquisition problem	Define systems problem	Define production problem
Value-system design	Identify mission need in terms of mission element	Identify program goals and objectives	Examine and validate program goals and objectives	Examine and validate program goals and objectives
System synthesis	Identify known-solution candidates	Identify candidate-system alternatives	Validate and refine system or program alternatives	Validate projected system alternatives
Systems analysis and modelling	Develop enemy-threat scenarios for time frame of required capability	Develop models to evaluate operational consideration, acquisition approaches	Develop models to evaluate system or program alternatives	Develop models to evaluate projected system
Optimization	Assess impact of not acquiring or maintaining capability	Evaluate candidate-system alternatives	Evaluate system or program alternatives	Evaluate full-scale development model
Decision making	*Milestone 0* (MENS approval cycle)	*Milestone I* (DCP approval cycle)	*Milestone II* (DCP approval cycle)	*Milestone III* (DCP approval cycle)
Planning for action (implementation of next phase)	Implementation of conceptual phase	Implementation of demonstration-and-validation phase	Implementation of full-scale-development phase	Implementation of production-and-deployment phase

[1]See *The Systems-Engineering Framework* (p. 67).

contained in the previous chapter. The analysis identified and defined a separate and distinct phase of the systems-acquisition process prior to approval of the MENS--the *Mission Analysis* phase; each logic-dimension step is identifiable as are activities within the phase.

The knowledge dimension encompasses the necessary professions and disciplines, including operations-research or management science, engineering, business, law, and military or naval science.

The stage approach,[1] used to evaluate and select R&D projects, may also be applied to systems acquisition. The stage approach is based on the sequential nature of the decision process associated with development programs. Normally these decisions are interspersed with stages of development activity (Brandenburg and Langenbert, 1969; Baker, Seigman, and Larson, 1971; Gear and Lockett, 1973a; and Gear and Lockett, 1973b).

Albala (1975) pointed out that a logical consequence of the sequential nature of the decision process is the recognition of milestones that represent the completion of different R&D phases. During the initial phases of the R&D process, the questions posed are primarily qualitative in nature, risk is very high, and investments are relatively small.

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[1]For the purposes of this report, a stage is defined as "A period of the R&D effort limited by reasonably clear boundaries determined by specific objectives and scope of work which is normally associated with a well defined decision point in the overall systems-acquisition effort" (Albala, 1975).

Toward the end of the R&D process, the richest and most accurate data are available, the degree of risk and uncertainty is at its lowest, and R&D costs are at their most significant levels. Each stage of the process may be characterized by four different factors (Albala, 1975):

1. Clear stage boundaries;
2. a progressively decreasing degree of risk and uncertainty;
3. a progressively increasing size of the investment;
4. an increasing length of time required for the completion of the stage.

The four characteristics noted above can be related to the systems-acquisition process. First, a meaningful analogy can be drawn between Albala's project stages and the phases of the systems-acquisition process. Secondly, as previously discussed, there is a decreasing degree of risk and uncertainty and an increase in R&D-investment costs as the program moves through the phases of the systems-acquisition process. Third, as a general rule, the time to complete each phase is progressively longer. Generalized curves depicting progressively increasing R&D program costs and progressively decreasing risk and uncertainty as a function of time and the systems-acquisition phases are presented in Figure 21. The figure also portrays the decreasing R&D costs at the end of the full-scale development phase and the increasing production costs at the beginning of the production phase.

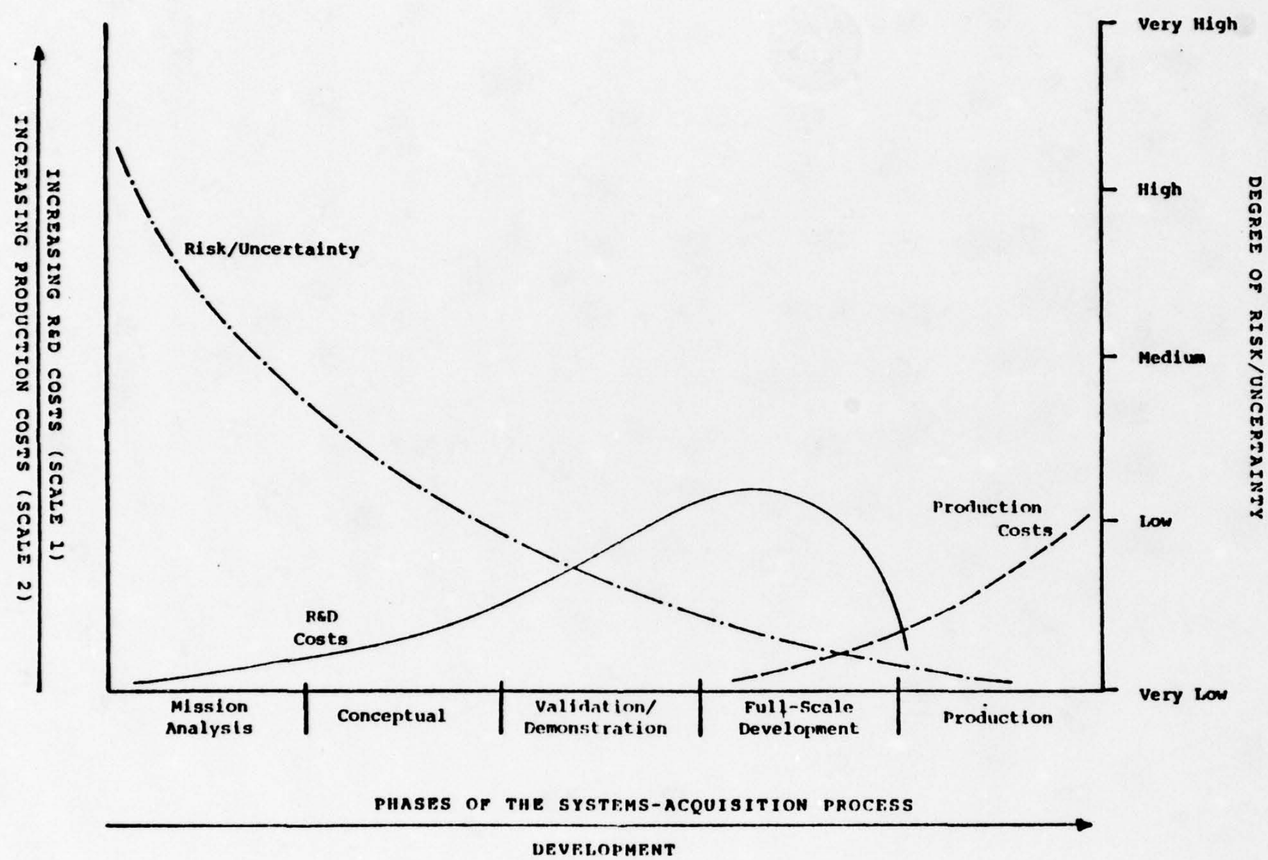

Figure 21. Generalized Program Costs and Risk/Uncertainty as a Function of the Systems-Acquisition Phases. R&D and production costs could differ by several orders of magnitude.

The systems-acquisition process may be cast into a stage approach representation as presented in Figure 22. The figure depicts the overall activities of systems acquisition in a DELTA chart format with a stage-approach structure superimposed upon it. The initial-analysis stage is followed by four interstage decision milestones alternating with the R&D stages that represent the phases of the acquisition process. Each phase includes all the steps of a logic dimension in systems-engineering as discussed in Chapter 3. The figure also includes a generalized breakdown of DOD responsibilities for the stage appoarch.

Consideration of the systems-acquisition process as a stage-approach activity, with its previously identified characteristic, is important to the analysis associated with each of the sequential decision milestones. Distinct analysis models, adopted to the particular phase (or stage), should be used for evaluation at different decision points rather than using the same model at all decision points (Albala, 1975; Gear and Lockett, 1973b; and Souder, 1973). This topic is addressed again in the *Development of the Systems Engineering Methodology* section (p. 183).

The following observations on the structure of the systems-acquisition process point the way toward the development of a systems-engineering methodology:

1. That the systems-acquisition process can be modelled with a systems-engineering framework;

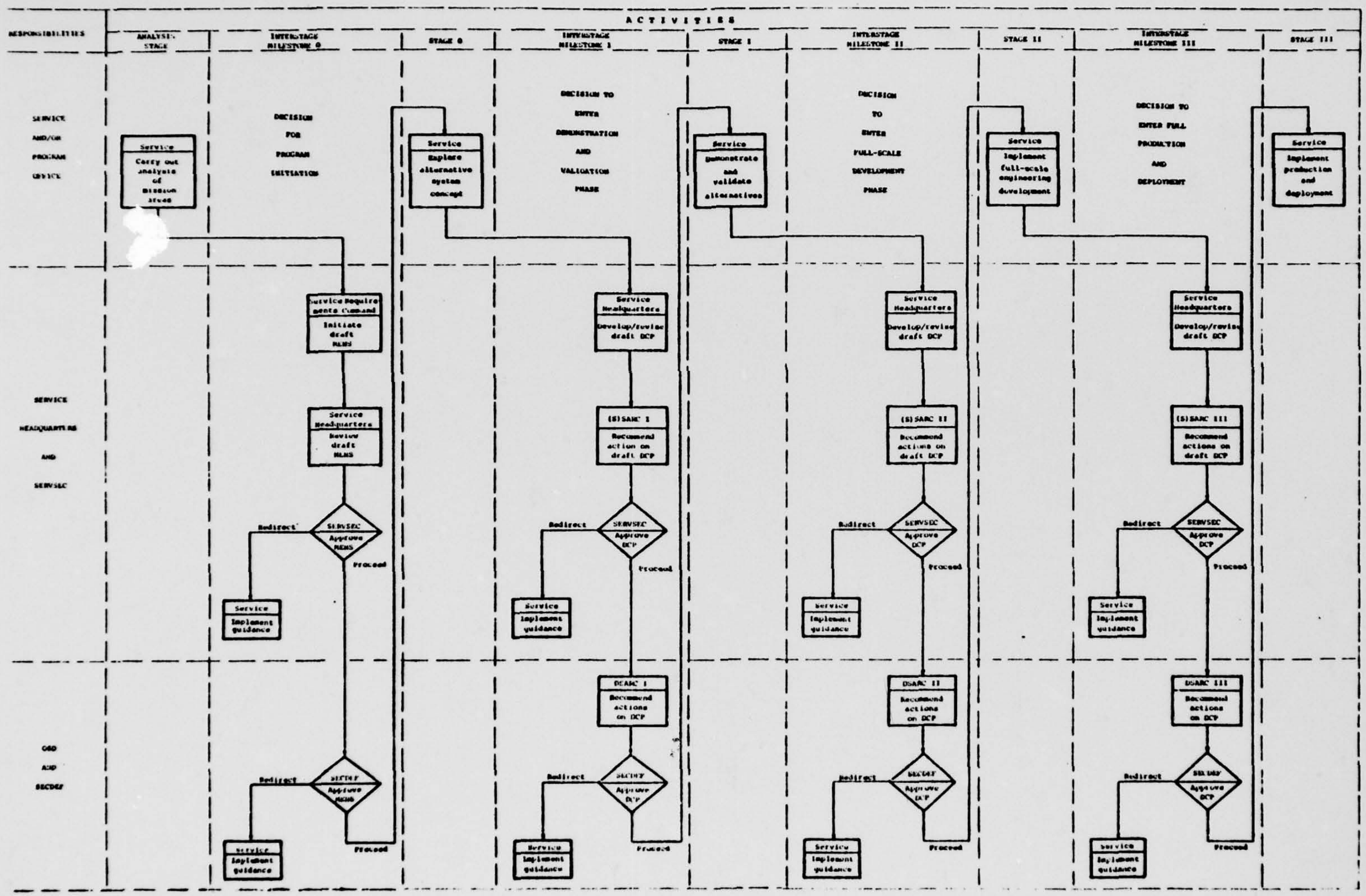

Figure 22. Stage-Approach Respresentation of the Systems-Acquisition Process.

2. that the activities carried out during each phase of the systems-acquisition process are repetitive, with each having a major-decision milestone that represents both the end of the previous phase and the beginning of a new phase;

3. that the systems-acquisition process is multistage and each phase is a separate stage of the overall development from mission analysis to production and deployment;

4. that the decisions associated with the systems-acquisition process are sequential and later decisions are highly dependent on previous decisions.

The Criteria and Organizational Considerations for Applying the Systems-Engineering Tools and Techniques

The identification of the criteria for applying the systems-engineering tools and techniques is important to the development of a systems-engineering methodology for the DOD's systems acquisitions. However, organizational characteristics must also be considered to understand how a systems-engineering methodology can be used for the systems-acquisition process.

A *criterion* is a standard, rule, or test by which a judgment of something can be formed. The criteria for selecting the appropriate analysis tool must incorporate the key characteristics of the systems-acquisition program to be evaluated. These key characteristics are identified when the acquisition program is viewed in the context of the

systems-engineering morphology and as modelled by the activities of the stage approach (Albala, 1975). Key program characteristics are noted below, with comments on each characteristic and a criterion to compliment each characteristic.

1. *Characteristic:* Data Availability for the Program

Comment: Data, from sources both internal and external to the organization, should be obtained with a minimum expenditure of time, money, and effort; both the quantity and quality of this data should be analyzed. The data-input-to-analysis models will not drive the cost accounting, program data management, and other data collection functions within the organization. Security requirements can restrict the availability of data.

Criterion: Analysis methods must be appropriate to the quantity and quality of available data.

2. *Characteristic:* Stage of the Acquisition Process

Comment: The levels of risk and uncertainty of many aspects of the program are governed by the stage (or phase) of the systems-acquisition program. The tradeoffs between quantitative and qualitative data are also dependent on the stage.

Criterion: Analysis methods must be consistent with features of the specific stage of the acquisition process.

3. *Characteristic:* Program Objectives

Comment: The objectives of the program are a key in determining what analysis procedures to use. Programs updating existing capabilities are analyzed through minimum validation processes. Programs for entirely new systems, or even revolutionary technology, require a much more thorough analysis effort (i.e., the Cruise Missile Program or the development of VSTOL aircraft).

Criterion: Analysis methods must be consistent with the overall objectives of the program.

4. *Characteristic:* A Step in the Analysis Effort for the Program

Comment: As each activity is analyzed, the analysis passes through the steps of the logic dimension of the systems-engineering framework. Each step has specific tools and techniques identified with it that should be used during that particular step. This association of tools and techniques with a particular logic-dimension step was recently documented (Sage, Warfield, Thissen, *et.al.*, 1978) and is based on the application of the systems-engineering methodology to the general policy problem.

Criterion: Analysis methods must be appropriate to the particular logic-dimension step being analyzed within the systems-engineering framework.

5. *Characteristic:* Extent of the Resources Required for the Program

Comment: The systems life-cycle costs and manpower requirements are two examples of the overall resource inputs to an acquisition program. The analysis effort for the program should be generally proportional to the overall resource requirements for the program.

Criterion: The effectiveness and reliability of the analysis efforts must increase as the resource inputs to the program increase.

The above criteria, *which must be adapted to the specific program being evaluated*, are important in selecting the tools and techniques to be used in a systems-engineering methodology. The second major factor in determining the nature, type, and degree of analysis to be performed is the organizational environment. In the DOD context, several organizations, including the System Program Office, the Service Headquarters, and OSD, could evaluate an acquisition program.

Several articles have been written on different aspects of the problem of using analysis procedures in decision making. Kast and Rosenzweig (1974) considered the behavioral aspects. Souder (1967) and Radnor, Rubenstein, and Tansik (1970) presented implementation procedures for operations and research in the R&D environments of government and business. The complexity of decision making in an R&D environment was also discussed by Hill and Ollila (1978); management

structure concerns for dealing with this complexity was addressed by Greenblott and Hung (1970). Polishuk (1976) specifically covered problems related to systems-engineering (interdisciplinary) policy research and management in the federal government.

Although these articles have provided a general frame of reference for using analysis procedures in decision making, they did not deal with the organizational aspects of selecting procedures. Based on the author's experience in Defense R&D, the following several organizational considerations affect the nature, type, and degree of an analysis selected to support decision making:

1. *Predisposition of the organization to use analysis procedures.* An organization's willingness to use systems engineering and management-science techniques is dependent on the history of use in that organization. These can be classified as follows: those that have successfully used the procedures, those that have used them with little or no success, and those that have not used them at all. The latter two are going to be unlikely to use any analysis procedures regardless of the demands of the specific decision-making situation. They may be reoriented to accept analysis support, but it will take time and patience on the part of the analysts.

2. *Position of the analysis unit within the organization.* As a general rule, the closer the analysis unit is in the organizational structure to the actual decision maker or policy maker, the greater the impact of the analyses. Filters between the managers and the analysts dilute the analysis effort proportionately. Organizational proximity will not guarantee the quality of the analysis, but it will enhance their leverage.

3. *Background and experience of the decision makers.* Their educational and professional backgrounds influence the degree to which the decision makers accept analysis procedures. Those with some technical background are usually willing to consider at least some sort of analysis assistance. Analysts must know the backgrounds of their decision makers.

4. *Availability of decision makers.* Time is a critical factor in any manager's professional day. Therefore, an analyst must adapt the analysis procedure to the available time of his decision maker. Analysis procedures that require excessive managerial time are not likely to be used.

5. *Mechanism used to transfer the results of the analysis to the decision makers.* The procedures associated with the decision process are important in determining what type of analysis procedures should be used. The one-shot briefing in which only the results of the analysis are presented cannot accomodate complex analysis procedures; those analyses which cannot be grasped by the manager in a short, one-half

hour briefing will not be used. On the other hand, if pre-briefings, informal conferences, or working groups are held first then more complex analyses may be used and acceptance is increased.

6. *Criticality of the decision to the organization.* The depth, extent, and nature of the analysis effort should be related to how important a particular decision is to the organization. Although the analysts should be aware of the decision makers' values, they must also be sensitive to the organization's value systems. Resources assigned to a particular program are not the only criteria for determining the importance of that program. Traditional mission-oriented needs, such as, tactical aircraft development for the Air Force, and external political influences are two other criteria for measuring a program's importance.

7. *Availability of resources for analysis.* The availability of resources for analysis, including qualified analysts, technical/administrative support personnel, and computer facilities, is a key factor in determining the type and extent of analysis. Managers for analysis units should be keenly aware of the planning and budgets of the organization so that ample provisions are made for future analysis efforts.

8. *Mode of organizational operation.* In this situation, the type of analysis to be performed is related to the type of policy roles being assumed by the policy maker within

the organization. Polishuk (1976) defined three policy roles: (a) "Downstream policy analysis": the policy maker makes an arbitrary decision about a policy matter and the organization is placed in an advocacy role to support this decision; (b) "Reactive policy analysis": external forces encroach upon the policy makers' areas of authority and the organization assumes a defensive role; (c) "Upstream policy analysis": the policy maker, in attempting to be a leader and manager exercises initiative instead of merely reacting to external forces. The policy maker wants to evaluate alternatives and desires comprehensive information about the area over which the position has management responsibility. The inexperienced analyst often anticipates working only in an organization that is operating in the third policy role. When the organization is in this policy role, the analyst is free to select the analysis procedures technically best fitted to the problem under consideration. However, all too often the organization is operating in one of the first two policy roles causing the analyst to use analysis procedures selected by organizational rather than technical criteria.

The organizational considerations developed above are addressed again in the section dealing with the implementation of the systems-engineering methodology.

The Emphasis of the Systems-Engineering Methodology

Those areas of the overall Defense systems-acquisition process that should be emphasized in developing a systems-engineering methodology are identified below from several perspectives. First, the perceived value system of the DSARC/(S)SARC panels are examined to see how a systems-engineering methodology could assist the panel members in obtaining their objectives. Second, the problem definitions (see Chapter 2, p. 36) are briefly reviewed to show the scope and focus of the methodology. Third, the structure and nature of the systems-acquisition process (see *The Nature and Structure of the Defense Systems-Acquisition Process*, p. 144) are used to identify the specific problems for analysis that are significantly important to management and particularly receptive to analysis efforts.

The perceived value systems for the DSARC and the (S)SARC panels are presented by the objectives tree of Figure 18 (p. 137). This figure shows that objectives 3.1 through 3.5 relate to considerations for DSARC dealing, respectively, with congressional relations, the direction of the Executive Branch, the Defense industry, the internal DOD systems-program management, and the international security.

These objectives 3.1 through 3.5 deal with problem considerations that must be integrated into the systems-acquisition decision process. However, these considerations

are difficult to address through systems-engineering because of the DOD perspective used in this disseration. Many of these problems can be solved by nonrigorous management techniques and behavioral approaches based on sound judgment, wisdom, and professional experience. In a recent article, Freund (1979) advocated the necessity to rely ultimately on judgment and experience in addressing complex issues. He further stated that analysis and research can only be used to a certain extent in addressing problems, then judgment must be called upon to resolve the issue.

The area of consideration that is fertile ground for applying systems-engineering analyses is that represented by objective 3.6 in Figure 18.--"to develop the best overall program of systems-acquisitions considering Defense-related constraints." The subobjectives under objective 3.6 deal with program selection and evaluation, criteria development, key-decision points, standardization requirements, and the development of supporting program documentation. These subobjectives point the way toward areas of emphasis for the systems-engineering methodology.

The problem definitions in Chapter 2 (p. 36) established the scope and focus of the problem to be addressed by the systems-engineering methodology. The problems are specifically oriented toward the DOD

environment and the major-decision milestones associated with a systems-acquisition process. The problem must be formulated within the existing policy framework as stipulated by OMB A-109 and DOD 5000.1/5000.2 (OMB, 1976a; Defense, 1977a, 1977b) but new policy initiatives should be addressed when appropriate. The methodology concentrates on the systems-acquisition decision process at the service-headquarters and OSD levels. The emphasis of these considerations in relation to the development of a methodology are summarized in the research problem statement for this effort: *To determine how the Department of Defense systems-acquisition process may be improved using systems engineering*. The emphasis of this study will be directed toward the four major-decision milestones (0, I, II, and III), the operation of the DSARC and (S)SARC, and the use of the Decision Coordination Paper (DCP) and Mission Element Need Statement (MENS) within the overall DOD-policy framework.

The problem definition and the perceived value system operative within the OSD and the Service Headquarters (specifically within the DSARC and (S)SARCs) point the direction toward the general problem areas where a systems-engineering methodology can be applied. However, it is the nature and structure of the systems-acquisition process (p. 144) that identify the specific problem elements to

which the analysis procedures of the systems-engineering methodology should be applied. These observations are reviewed below and specific problem elements are identified for analysis within the systems-engineering methodology.

In reviewing the observations on the nature of the systems-acquisition process, the first major area of emphasis to be identified is the development of the MENS. This document presents the results of the initial problem-definition step of the systems-acquisition process. It is also used as the basis for approving new starts and is, therefore, a critical document. Because of the importance of this document and of the clarity of its contents (see Defense, 1978b), the format of the MENS must be improved. Therefore, the first task of developing the systems-engineering methodology is to outline a more rigorous buy yet flexible format for the MENS.

This initial task in developing the methodology involves two of the recommended DOD systems-acquisition-policy initiatives covered in the observations on the nature of the systems-acquisition process (p.144). Specifically, it is related to the recommended policy initiatives on formalizing the *de facto* mission-analysis phase into an official phase of systems acquisition. This task also relates to the policy initiative for a more clearly defined problem-definition

approach to the MENS. Both these policy initiatives are specifically addressed in *Development of the Systems-Engineering Methodology*, (p. 183).

Two of the other recommended policy initiatives presented in the observations on the nature of the systems-acquisition process (p. 144) are: (1) the adoption of a more flexible overall approach for the process and (2) the integration of the OMB A-109 (1976a) policies into the programming requirements of the PPBS and the congressional budget cycle. Since these issues have been considered by OSD and are included in the revised versions (December 18, 1978) of DOD Directives 5000.1 and 5000.2, they are not addressed again in this paper.

The second major area of emphasis for the methodology is that of trading off the various potential programs early in the acquisition process. A very subtle type of tradeoff currently takes place at the Milestone 0 decision point. The mission-element need becomes a yardstick for measuring requirements; the existing capability is measured against this yardstick. If the capability falls short of the yardstick, then, almost by definition, some new start is required whether it is a completely new acquisition program or a major modification.

The problem, of course, is that the programs are not traded off, one against the other, until further into the systems-acquisition cycle when funding requirements are more readily identifiable. They are traded off when

funds are constrained and with little management control. Therefore, the second task of developing the systems-engineering methodology is to establish a procedure for evaluating and selecting the programs to be approved for official program initiation. This is the final policy initiative presented in the observations on the nature of the systems-acquisition process (p.144). The policy implications of the selection and evaluation procedures of this task are addressed in the *Development of the Systems-Engineering Methodology* (p.183).

The final major area of emphasis for the methodology as indicated by the observation on the nature and structure of the process is that of addressing the major-decision *Milestones I, II, and III.* Two types of decisions are considered at Milestones I, II, and III that could be analyzed with systems-engineering procedures. The first type deals with evaluating and selecting alternative-candidate solutions to be advanced to the next phase of the acquisition process. This decision begins in the systems-program office and continues through the DSARC/(S)SARC process to the OSD level. The second type of decision is the go/no-go determination for an overall program to proceed to the next phase. This decision is usually forwarded through the (S)SARC and DSARC with recommendations to the SERVSEC and SECDEF, respectively. The first type of decision provides input to the second decision.

The relationship of the two types of decisions to the major-decision milestones and their importance to the

overall systems-acquisition process are given in Table 8. This shows the similarity between major Milestone I and II where both types of decisions must be considered. When the nature of the systems-acquisition process is considered as a *stage-approach* problem, the decisions at Milestone I and II are made when there is still risk and uncertainty in the program and during the transition from qualitative to quantitative data. The decision situations at Milestones I and II may be contrasted to the situation at Milestone III. At the latter, only one type of decision must be made--the go/no-go determination for production. This decision is also made at the end of the development effort when risk and uncertainty are normally lowest and quantitative data is most available.

Considering the differences, there are really two distinct areas of analysis related to the major-decision milestones: the analyses required for Milestones I and II, and the analysis required for Milestone III.

Therefore, four separate areas have been identified for emphasis in the systems-engineering methodology. Each area of emphasis has an analysis task associated with it that is addressed in the development of the methodology. These analysis tasks are:

1. To develop a more rigorous and well-defined MENS;
2. to develop an analysis procudure to trade off newly identified programs (as represented by their MENS) early in the systems-acquisition process.

TABLE 8

TYPES OF DECISIONS CONSIDERED AT DECISION MILESTONES I, II, AND III

Major-Decision Milestone	Decisions: To Evaluate and Select Alternative Candidate Solutions to Advance to Next Phase	Decisions: Go/No-Go Determination to Advance Overall Program to Next Phase
I Approval to proceed to demonstration-and-validation phase	Most critical because of number of alternatives to be considered	Less critical than Milestone III; projected fund requirements are lower, production decision is not made
II Approval for production and deployment	Less critical than Milestone I; less alternatives are considered	Most critical; approval to proceed should not be granted unless production is very probable
III Approval for production and deployment	Not required	Almost as critical as Milestone II; final review before funds for production and deployment are committed

3. to develop an analysis procedure to support the DSARC/(S)SARC decision process at major-decision Milestones I and II;

4. to develop an analysis procedure to support the DSARC/(S)SARC decision process at major-decision Milestone III.

Development of the Systems-Engineering Methodology

Methodology has been defined (Sage, 1977) as an open set of procedures that provides the means for solving problems. This definition can include three separate components related to developing and using the methodology. First, the problems to be addressed by the methodology must be identified. This requires studying the overall systems problem with all its inherent policy and organizational considerations and isolating those specific problem areas where the application of analysis procedures would be most appropriate and beneficial. Second, the types of systems-engineering tools and techniques must be determined for the specific problem areas. Third, the most appropriate systems-engineering analysis procedures must be selected and initiated.

The accomplishment of these three requirements presupposes the establishment of several systems-engineering teams to develop and implement the methodology. These teams must be located within OSD and at the headquarters of the several military services. A detailed discussion of the

functions and characteristics of these projected systems-engineering teams is presented in the next section.

The previous section, *The Emphasis of the Systems-Engineering Methodology*, (p.175), identifies specific problem areas of the overall systems problem for the application of analysis procedures. The actual means by which this was carried out is graphically portrayed in the DELTA chart of Figure 23. This chart includes the analysis efforts presented in several sections of this dissertation. However, the chart also shows a general set of procedures that can be applied to the study of complex decision-making processes in large organizations. These procedures follow the logic-dimension steps of the systems-engineering morphology and result in the identification of the specific analysis tasks that need to be performed. The chart effectively presents a graphical algorithm for the selection of the analysis tasks of the methodology. One feedback loop is included in the chart to indicate that the need to revise the organization's policy and procedures may be identified through the analysis associated with developing the systems-engineering methodology. In a more detailed DELTA chart, multi-feedback loops could be used for this set of procedures. The procedures of Figure 23 assume a close relationship between the analyst and the organization.

The second requirement for developing the methodology is to determine the appropriate systems-engineering tools

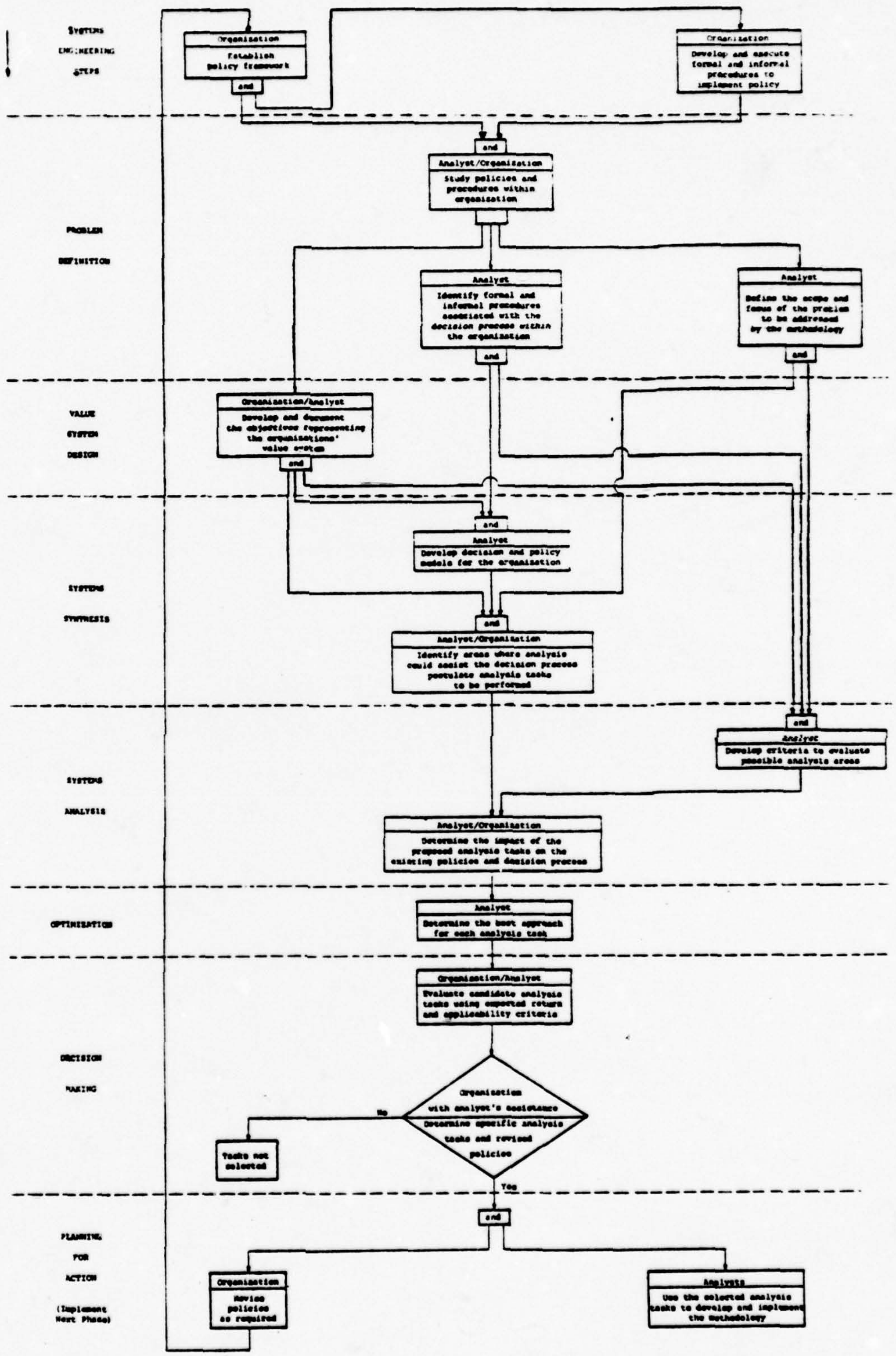

Figure 23. The Identification of Specific Analysis Tasks to be Performed within the Systems-Engineering Methodology.

and techniques to be applied to each previously identified problem-analysis area. The selection criteria associated with the program characteristics and the organizational considerations for selecting analysis procedures (see *The Nature of the Defense Systems Acquisition Process*, p. 144) are used in determining which tools and techniques should be used in addressing a specific analysis task.

The systems-acquisition process, as modelled by the systems-engineering morphology (Chapter 3, p.62), is of particular interest in this section. The logic dimension of the systems-engineering morphology is viewed more generally to assist in the current research. Sage, Warfield, Thissen, *et al.*, (1978) indicated that it is convenient to aggregate the seven steps of the logic dimension of the morphology into three more general steps. First, the problem-definition, value-system-design, and system-synthesis steps may be aggregated into a single step called *input description and specification*. The systems-analysis-and-modelling step and the optimization of each alternative step can be combined into a single step called *impact assessment*. The decision-making and planning-for-action steps can also be collected in a single step called *output specification and interpretation*. Figure 24 illustrates the iterative feedback nature of these three generalized steps. Figure 25 illustrates the hierarchical structure associated with the systems engineering in accordance with the contextual relation *is a component of*. Each analysis

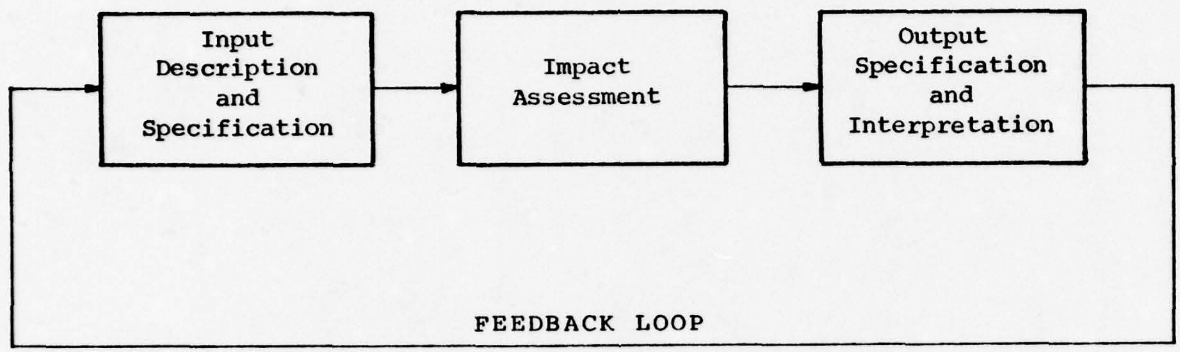

Figure 24. Iterative Nature of the Three Primary Steps in the Systems-Engineering Processes (SOURCE: Sage, Warfield, Thissen, *et al.*, 1978).

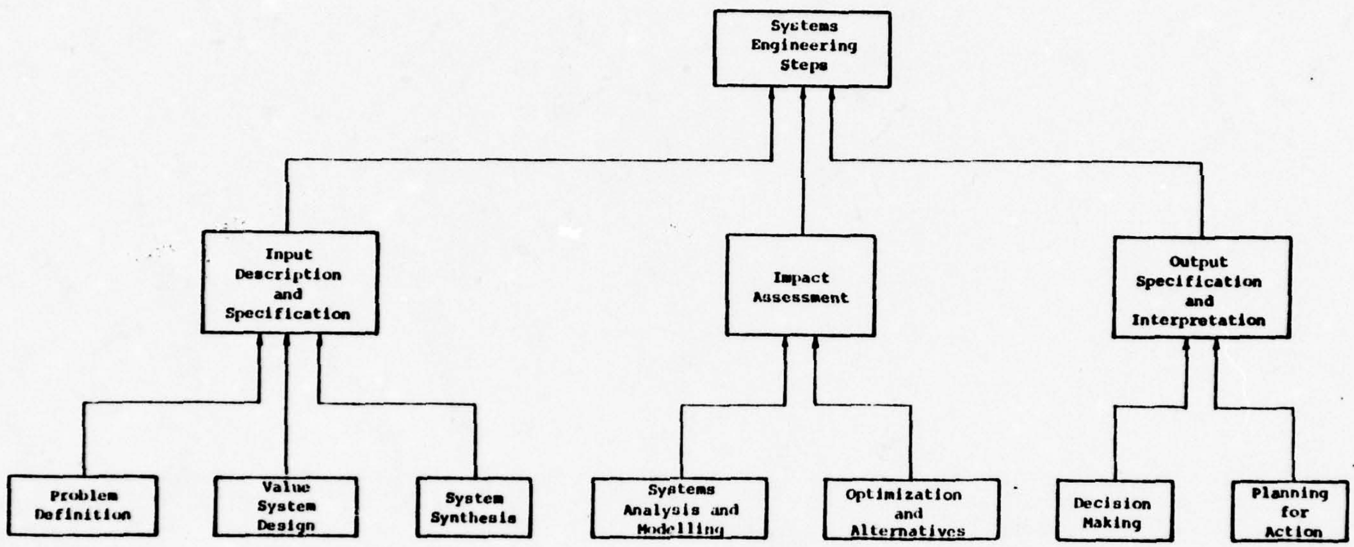

Figure 25. Hierarchical Structure of the Steps of Systems Engineering (Source: Sage, Warfield, Thissen, et al., 1978).

procedure addressed in this section is associated with one of the three generalized systems-engineering steps discussed above.

The third requirement for developing and using the systems-engineering methodology is the need to implement the methodology. This requirement will be addressed in the next section, *Implementation of the Methodology*, (p. 237).

In the previous section, four specific problem areas of the systems-acquisition decision process were selected for emphasis in the systems-engineering methodology. Each specific problem area must be addressed by a separate task to develop appropriate analysis procedures. The four tasks developed for the analysis procedures are outlined below.

Development of Analysis Procedures

Task #1: To Develop a More Flexible, Better-Defined Documentation Process for the MENS

Introduction

The MENS is intended to document the operational need for a new or improved mission capability. A mission need arises from a projected deficiency (or obsolescence) in an existing system, a technological opportunity, or an opportunity to reduce operating cost. There is not anything particularly new about the concept of identifying, defining, and documenting operational requirements based on the missions of the different services. The concept of relating R&D

programs sponsored by the military services to future military-mission requirements was described by Clarke (1967). Jordan (1974) discussed the operational-requirements determination process for major Naval weapon systems. He discussed such terms as *general operational requirement* (GOR), *specific operational requirement* (SOR), and *tentative specific operational requirement* (TSOR), all of which described naval-operational requirements during the late 1960's and early 1970's.

The significant changes in the overall development of operation requirements with the advent of the OMB A-109 (1976a) and the MENS (Defense, 1978b) have been in the processing and approval of the requirements document. Previously, this document was approved by the separate services, now the MENS must be approved by the SECDEF.

Because the requirements for the MENS are not as clearly defined as they could be, the characteristics of the mission-element need are not being documented in the most efficient possible way. This task will present an analysis procedure for a more clearly defined mission-element need.

Relationship to the generalized systems-engineering steps

The material presented in Chapter 3 (p.62) shows that developing and documenting the MENS is the first general step (input description and specification) of the systems-engineering framework for the mission-analysis

(program-planning) phase of the systems-acquisition process. The MENS is the foundation document for the possible approval and implementation of a major systems-acquisition program. It is the basis for the major-decision Milestone 0 and also must be reviewed and updated at each subsequent major-decision milestone to insure that the operational need is still valid.

Analysis-procedure selection considerations

Based on the program characteristics, there are two important considerations, data availability and program objective. Data availability is limited in quantity and quality; the program objective at this point is to clearly define the problem in an integrated, identifiable, and visible manner. The availability of resources for analysis is particularly important to this task. Most of the MENS will be developed by the service and its headquarters. There should be sufficient analysis resources to accomplish this step thoroughly.

Analysis Procedure

As noted in *The Systems-Engineering Framework and the DOD Systems-Acquisition Process* (p. 100), the development and review of MENS during the mission-analysis phase of the systems-acquisition process represents the program-planning phase of the systems-engineering framework. In particular, DOD Directive 5000.2 requires that the MENS address such areas

as mission area (objectives), needs, existing capabilities, constraints, assessment of impacts of not acquiring the projected capability, and plans to identify and explore competitive alternative systems. These requirements of the MENS are very similar to the products that would be anticipated from carrying out the first three steps of the logic dimension of the systems-engineering framework: problem definition, value systems design, and systems synthesis.

Hill and Warfield (1972) developed a technique by which the first three steps of the program-planning phase of systems engineering could be accomplished for complex programs with multiple relationships. This technique was called Unified Program Planning and it set forth a graphical approach by which the steps of the program planning phase could be addressed as a connected set. Because of the complexity of the Defense programs that are evaluated by the systems-acquisition process, Unified Program Planning was chosen as the means to carry out the mission-analysis (program planning) phase of the process and thereby develop the MENS. Interpretive Structural Modeling (Warfield, 1976) would extend the capabilities of Unified Program Planning and would provide a more efficient and explicit method of handling the generated data.

Results and anticipated benefits

Since the various areas of concern addressed by the MENS and outlined in DOD Directive 5000.2 (Defense, 1977b) are the goals of this analysis task, the threat, existing and planned capabilities, and the mission will all be addressed. However, these and other considerations will be studied more comprehensively than envisioned by the current DOD directives. The products for the three steps are listed from Hill and Warfield (1972):

1. *Problem Definition Products.*

   a. A well-conceived title for the problem or issue.

   b. A descriptive scenario explaining the nature of the problem and how it came to be a problem, presenting as much history and data as can be prepared with available resources.

   c. An understanding of what disciplines or professions are relevant to the problem.

   d. An assessment of scope.

   e. A determination of the Defense sectors involved.

   f. An identification of the people to be involved in the problem-solving situation.

   g. An identification of need.

   h. An identification of alterables (those elements in the system that are subject to change.)

   i. An identification of major constraints.

   j. A breakdown of the problem into relevant elements.

   k. Some isolation of the subjective elements of the problem.

2. *Value System Design Products.*

   a. A set of objectives for the program arranged in a hierarchical structure.

   b. A set of graphical linkages which would relate the objectives to needs, constraints, and alterables.

c. A set of measures defined on the objectives by which to measure the attainment of objectives.

3. *System Synthesis Products.*

a. A graphical representation of the relationships between the planned activities and the program activities.

b. A graphical representation of the interactions between the planned activities and the program constraints.

c. A measurement system required for relating the progress of the activities to the attainment of the objectives.

Results from this analysis procedure would more clearly define a mission-element need with well-identified and highly visible problem-element interactions and interrelationships.

Capsule description of the analysis procedure

Normally this general step of the system-engineering morphology requires a group to analyze the overall mission-element need and any projected associated program. This group would consider the holistic problem in a mode of thinking called *outscoping*. Hill and Warfield (1972) defined outscoping as

> A deliberate group attempt to embed the problem or issue in the next larger problem or issue iteratively in order to expand the scope until the problem or issue is seen in an encompassing context.

When this context is reached, the group can identify the various elements of the several problem sets and the interactions among them.

The problem arises as to how to develop, record, and communicate the products of a group. Graphics may be used for this purpose, particularly trees and matrices, to unify the output products enumerated above.

In the problem-definition step, the various relationships between constraints, alterables, needs, and Defense sectors must be addressed. This can be done by self-interaction (Figure 26) and cross-interaction (Figure 27) matrices, which show interactions between elements of the same set or interactions between elements of differing sets, respectively. Levels of interaction can also be shown and the overall relationship of the several sets can be portrayed as shown in Figure 28. This means of presentation allows the following products of the problem-definition step to be graphically portrayed at one time.

1. The defense sectors involved;
2. the identified needs;
3. the identified alterables;
4. the identified major constraints;
5. a description of the interactions among the relevant elements of the problem.

In the value-system design phase, objectives trees similar to those used elsewhere in this dissertation should be used to portray the hierarchical relationships among the objectives for the program or system. This approach would be useful in placing a mission-element need in the context of its mission area. A specific syntax should be used to form an objective: *infinitive verb + object word* (or phrase) + *constraints*. The objectives tree is formed by carrying out the following rules (Hill and Warfield, 1972):

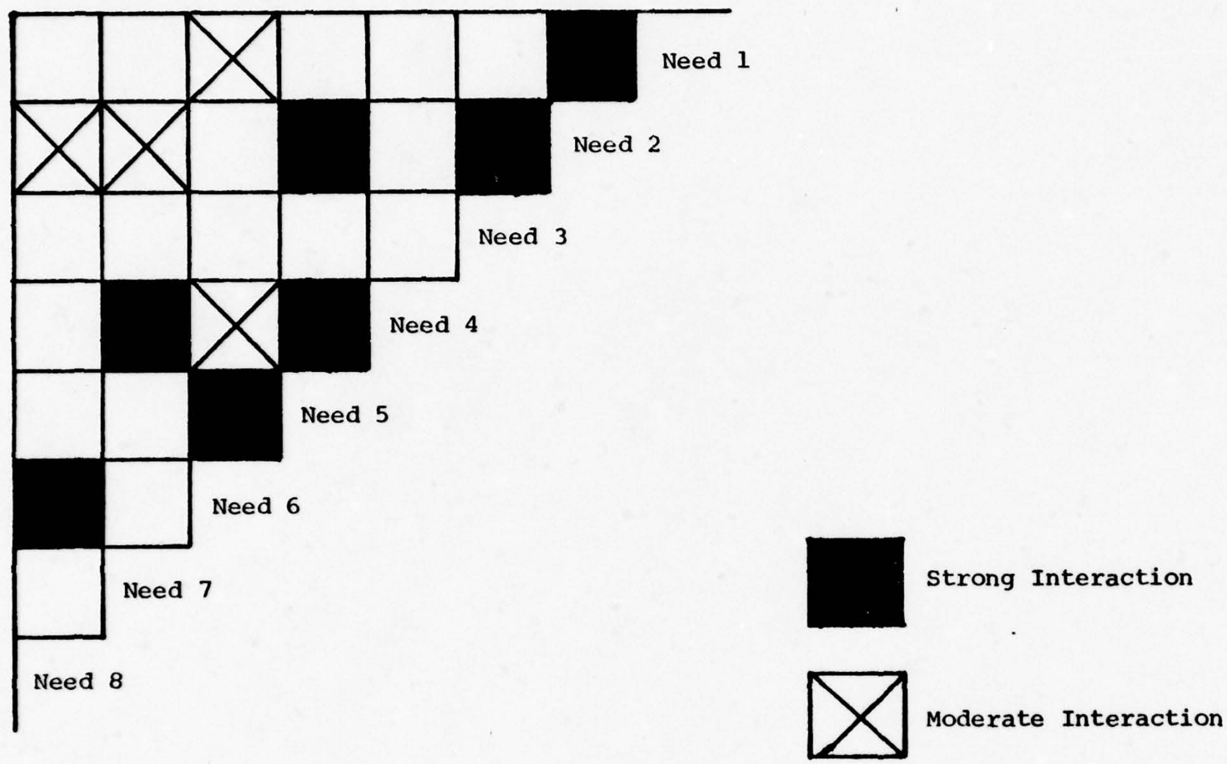

Figure 26. An Example of a Self-Interaction Matrix (adapted from Hill and Warfield, 1972).

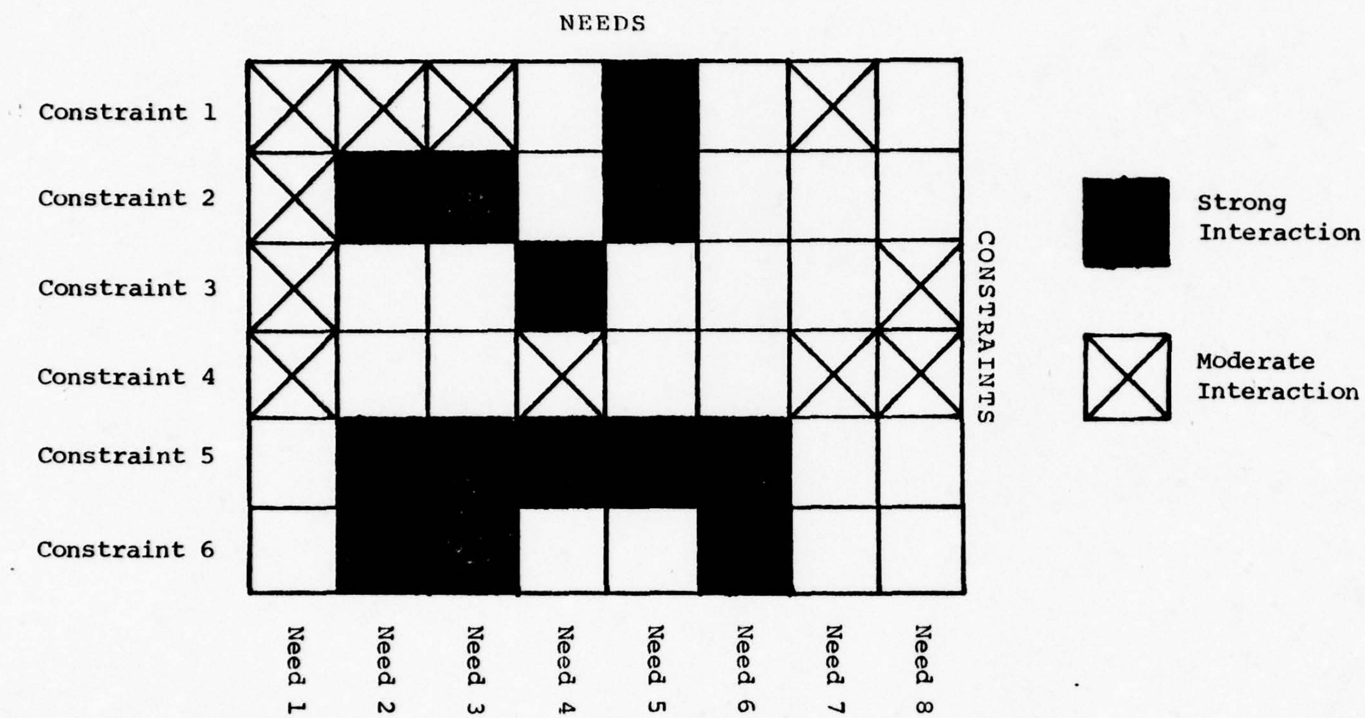

Figure 27. An Example of a Cross-Interaction Matrix (adapted from Hill and Warfield, 1972).

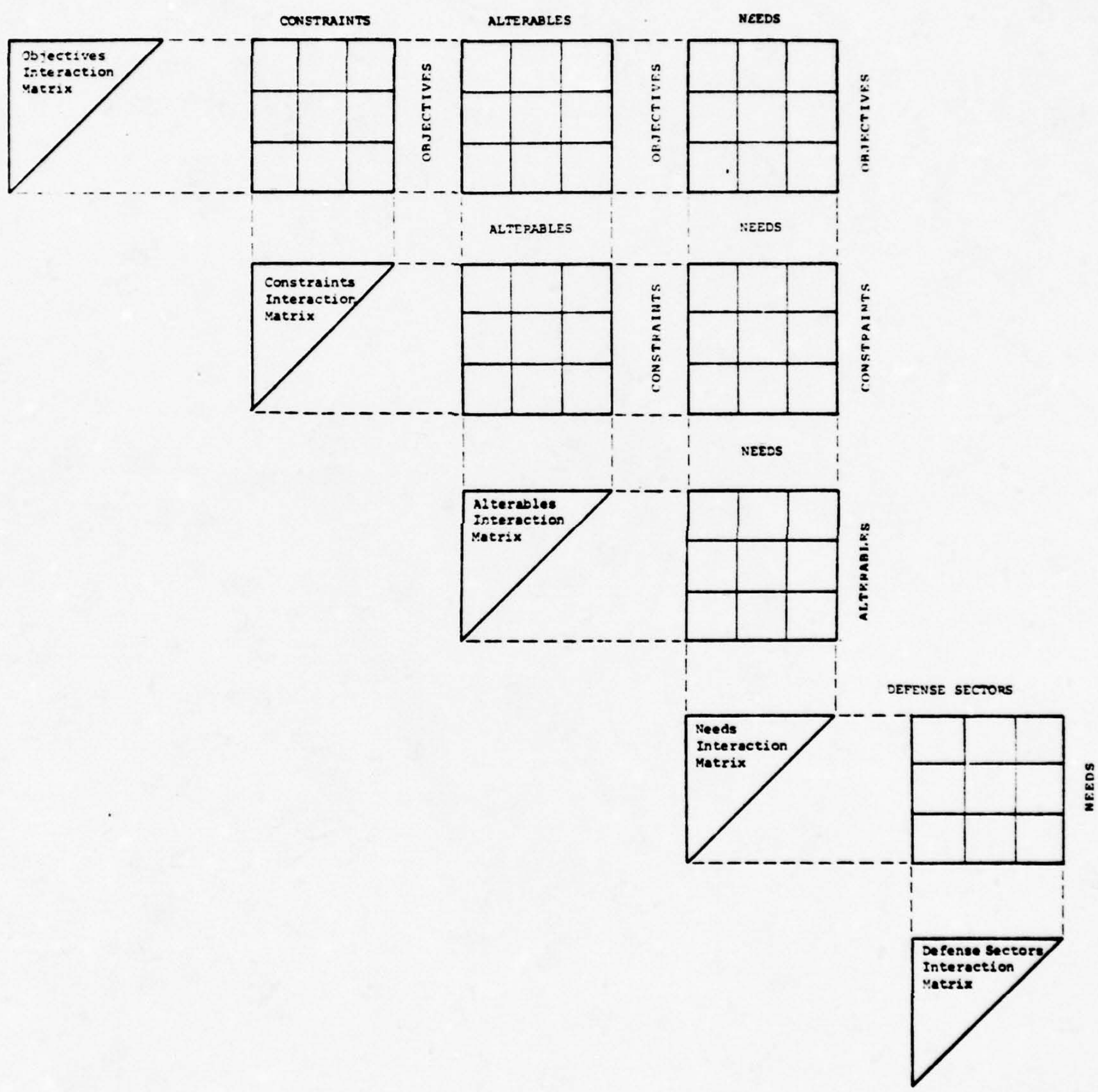

Figure 28. Interaction of Objectives with Constraints, Alterables, Needs, and Defense Sectors (adapted from Hill and Warfield, 1972).

1. Write each objective within a box to form the vortex of a tree.

2. Connect two boxes containing two objectives, if achievement of one of the objectives contributes directly to achievement of the other.

An example of an objectives tree is shown in Figure 4 (p. 45). A cross-interaction matrix can be used to show the interrelationships between the objectives measures and the objectives as shown in Figure 29. The products of the system synthesis may be represented by interaction and cross-interaction matrices as shown in Figure 30.

Input requirements

The input to this analysis process comes in the form of thoughts, concepts, ideas, and information about the various problem elements. The information is associated with the MENS components, such as, the enemy threat and the performance characteristics of existing capabilities. However, the thoughts, concepts, and ideas must come from the personnel involved in the problem-definition effort.

Several methods, including brain writing, brain storming, and the DELPHI method, could be used to generate the required problem elements. A procedure particularly applicable to the DOD environment is the Nominal Group Process (NGP). This is a structured group meeting where six to ten people sit around a table in full view of one another. Each individual writes his own ideas on a pad without consulting any other member of the group. After approximately five to

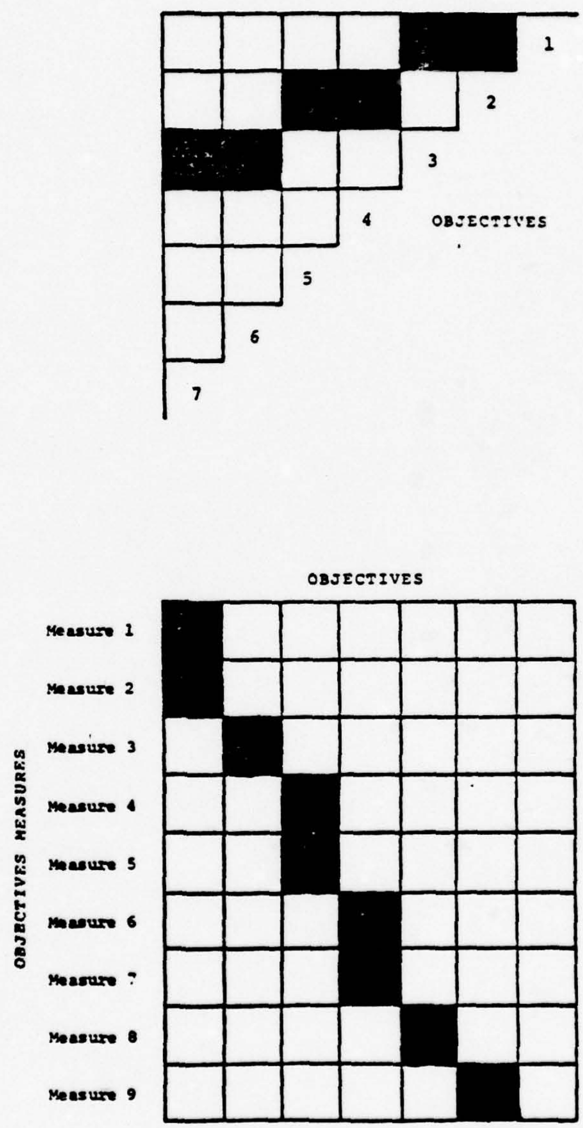

Figure 29. Interrelationships Between the Objectives Measures and the Objectives (adapted from Hill and Warfield, 1972).

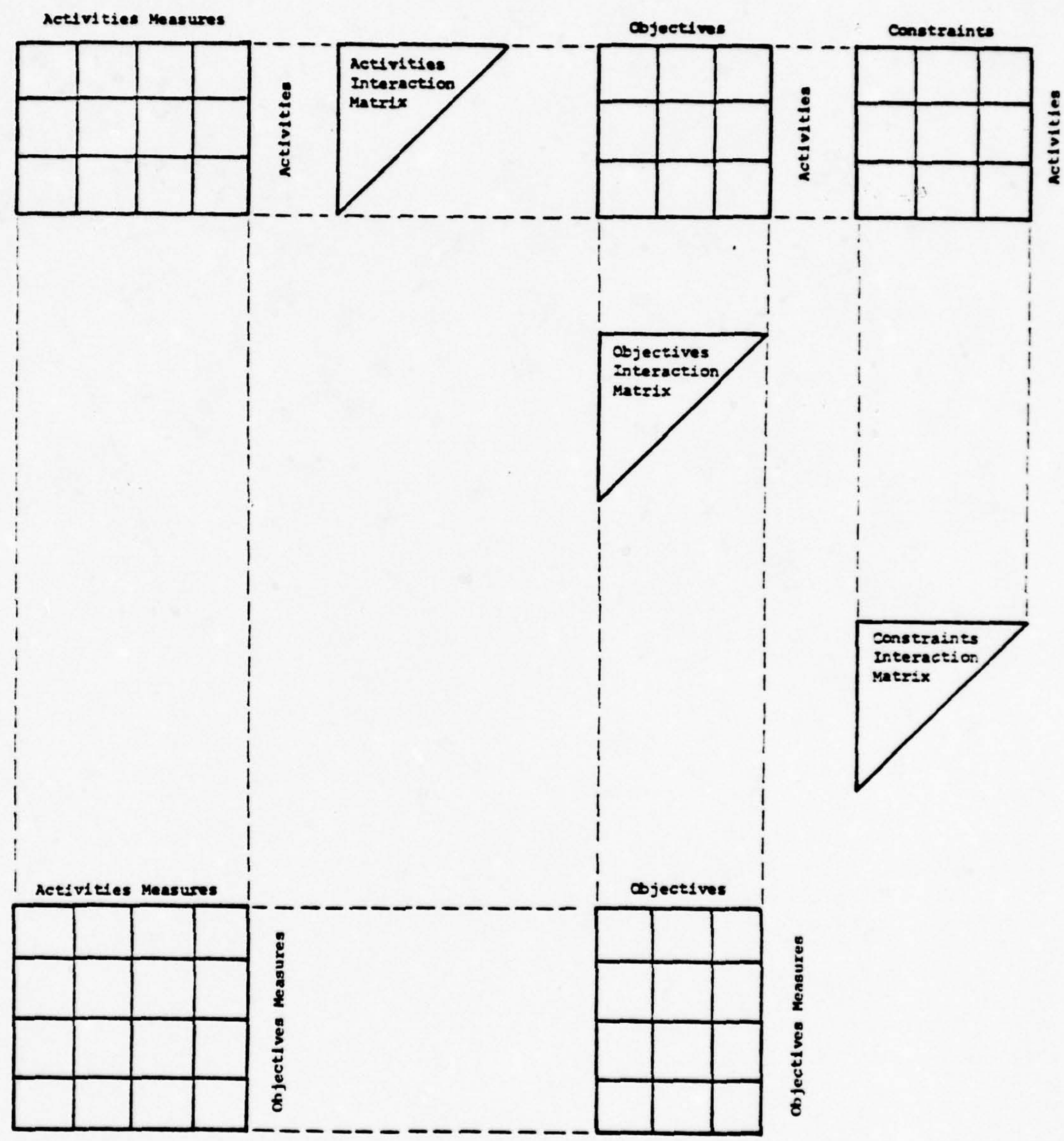

Figure 30. Linkages of the System-Synthesis Phase Represented by Interaction and Cross-Interaction Matrices (adapted from Hill and Warfield, 1972).

fifteen minutes, each person, in his turn, presents a single idea from his personal list. The ideas are recorded on a flip chart; this process continues until each member has divulged his list of ideas. Next, the ideas listed on the flip chart are clarified and expanded. After a thorough discussion, each member of the group selects his own choice of ideas indicating his order of priority (Delbecq, Van de Van, and Gustafson, 1976).

Operational and analysis assumptions

From the operational standpoint of DOD, it is assumed that an emerging mission-element need requires a more clearly identified, properly developed, and meaningful document. It is also assumed that there are service personnel who have a qualitative understanding of the mission area and are willing to develop a MENS. Validation of the analysis procedures is not dependent on any strong underlying theoretical assumptions. However, it is assumed that the various sets of problem elements (i.e., alterables, constraints, and needs) can be identified and the interactions amount them determined.

Locations of analysis effort

The vast majority of the work required to develop the MENS using the Unified Program Planning approach (Hill and Warfield, 1972) could be accomplished at or below the service-headquarters level. Some services have requirements commands to carry out much of the analysis effort. Inputs to the

threat assessment must come from the various intelligence agencies, such as, the Central Intelligence Agency (CIA), Defense Intelligence Agency (DIA), and the National Security Agency (NSA). The inputs for existing capabilities could come from the operational and logistical commands of the services.

The role of the decision makers

The top-level managers in OSD or the service headquarters would have very little involvement in the initial analyses of this task. However, as preparation for the MENS advanced, top-level DOD managers should become more actively involved. This involvement in the analysis effort would provide the decision makers with the necessary background for an evaluation of the MENS as described in the next task.

The role of the systems-engineering teams

The systems-engineering teams to be used at the service headquarters would be responsible for developing the procedure for implementing the Unified Program Planning approach to the development of the MENS. They would also be responsible for providing technical support to the various groups involved in developing the MENS. Finally, they would review each MENS prior to its submission to the SERVSEC and SECDEF. This review should be designed to insure consistency in technical approach, format, content, and level of detail. This team would then assist the decision makers in understanding the analysis procedures required to develop the MENS.

Cost and time considerations

The implementation of the Unified Program Planning approach to MENS development should not cause significant increases in the costs or time of the overall process. The existing operational-requirements analysis personnel, assisted by the projected systems-engineering teams, should be able to develop and document a MENS using the suggested approach. Once personnel become familiar with the standardized analysis approach of Unified Program Planning, the MENS-development time should be shortened. The existing question as to what constitutes a MENS would be alleviated by this approach.

Policy implications

The recommendations embodied in the projected analysis procedure relate only to the development procedures and format for the MENS. There is no intent here to revise the MENS processing and approval cycle. Therefore, the policy implications are minimal and relate only to the requirement to revise DOD Directives 5000.1 and 5000.2 to reflect the Unified Program Planning approach to developing the MENS.

References to the literature for the analysis procedure

The Unified Program Planning approach was originally documented by Hill and Warfield in 1972. Warfield placed this approach in a larger context in his *Societal Systems* text in 1976. A recent article by Hill and Ollila (1978) addressed the topic of complex decision-making processes by extending

the interaction-matrices approach. The Nominal Group Process outlined above, as a means to develop inputs for the Unified Program Planning procedure, has been discussed by Delbecq, Van de Van, and Gustafson in their text, *Group Techniques for Program Planning* (1976).

Task #2: To Develop an Analysis Procedure to Trade Off Newly Identified Mission-Element Needs Early in the Systems-Aquisition Process

Introduction

This task addresses the development of an analysis procedure to provide means of evaluation at the major-decision Milestone 0. This evaluation would enable the tradeoff of newly identified mission-element needs and determine if a program should proceed to the conceptual phase. The task is addressed in the DSARC objective presented in Figure 18 (p.137) that states

> to insure that the minimum set of systems-acquisition programs necessary to meet National Defense requirements are approved and the low priority, least affordable systems are cancelled.

The recommended approach to this evaluation process has several steps. First, semiannual MENS submission dates would be established; as a draft MENS (potential programs) is submitted by a service, it would be assigned a number specifying the particular year and group. At the next six-months-review period, it would be considered. Second, on a semiannual basis, OSD would review and evaluate all the

MENS (potential programs) using the standardized evaluation criteria and procedures developed below. Finally, programs showing sufficient merit would be advanced to the conceptual phase.

This approach would be particularly beneficial during the next several years as all potential programs go through the MENS process for the first time. The approach would provide important features to the systems-acquisition process. It would enable at least an attempt to be made toward trading off the candidate programs and determining their relative priority. This approach should secure the objective of developing only the required minimum set of systems-acquisition programs and cancelling the low-priority programs. Finally, each approved systems-acquisition program would be assigned specific year groups, which would allow it to be more effectively integrated into the Congressional budgetary cycle and the PPBS.

Relationship to the generalized systems-engineering steps

Considering the systems-engineering framework analysis in Chapter 3 (p.62), the procedure outlined in this task addresses two of the general steps of the systems-engineering logic dimension. The impact-assessment step is addressed by the structuring of the problem, criteria identification, and program-evaluation efforts associated with the task. The output-specification step is addressed by the decision process

used to select the programs to be advanced to the conceptual phase.

Analysis-procedure selection considerations

Based on the program characteristics, two important considerations are data availability and the stage of the acquisition process. Data availability at this point is rather limited and data are qualitative. Two organizational considerations are important in selecting an analysis procedure. First, the availability of the analyst must be considered because much of the structuring of the analysis problem will, of necessity, have to be done within OSD where the decision to approve the programs is to be made. Second, the availability of top-level OSD decision makers must be considered. It would be inappropriate to select a procedure that placed unjustified demands on the professional time of these decision makers.

Analysis procedure

The analysis procedure selected for application in this particular task is that of the Justification (Viability/Objectives) Checklist as developed by Bradbury, Gallagher, and Suckling (1973). This particular approach was selected because it would require only qualitative information. This procedure would therefore support both the generalized steps of impact assessment and of output specification and interpretation for the mission-analysis (program-planning) phase.

Results and anticipated benefits

This analysis procedure would result in:

1. A set of comprehensive checklists that would qualitatively describe the various aspects of each program under consideration.

2. A derived priority list of all the programs under consideration.

3. An assessment of the potential programs that had not met a preselected set of standards and were deleted.

This procedure would increase the ability to discriminate among the various potential programs and more efficiently evaluate their viability and overall contribution to the national defense.

Capsule description of the analysis procedure

Several steps would be required to assess the various potential programs by using the checklist procedure. First, a preanalysis effort should be directed toward identifying and defining the evaluation problem. This step should include the needs, constraints, alterable quantities, and objectives. Evaluation areas (Table 9) and associated factors would then be determined. Each factor would have levels of goodness associated with it dependent on the evaluation area. A baseline subset of factors and levels of goodness would be established as the minimum acceptable standard for the approval of a program. The decision maker would then assess each factor

TABLE 9

FACTORS & ANALYSIS PROCEDURES TO ASSIST IN THE EVALUATION, SELECTION & APPROVAL OF DEFENCE SYSTEMS ACQUISITION PROCEDURES BASED ON THE STAGE OF THE PROCESS

EVALUATION AREAS & ASSOCIATED FACTORS	*MILESTONE 0*		*MILESTONE I & II*			*MILESTONE III*
	Program Initiation & Approval for Conceptual Phase		Approval for Validation Demonstration Phase Approval for Full Scale Development Phase			Approval for Production & Deployment
	EVALUATION PROCEDURE: Viability/Justification Checklist		EVALUATION PROCEDURE: Scoring Models			EVALUATION PROCEDURE: Multiattribute-Utility Theory
			Low	Medium	High	
Mission Element Need						
Comparative Need						
Tactical threat	Low	High				
Strategic threat	Low	High				
Timing of need	Noncritical	Critical				
Single-service requirement	-	Yes				
Multiservice requirement	No	Yes				
NATO requirement	No	Yes		See Comment Below		See Comment Below
Degree of affordability	Low	High				
Existing Capability						
Manpower	Normal	Excessive				
Logistics support	Normal	Excessive				
Performance	Adequate	Inadequate				
Life cycle	% Remaining	Expired				
C^3 considerations	Adequate	Inadequate				

Technical Assessment

R & D Status						
Project relation to other DOD/service projects	Incompatible	Compatible	Not Related	Related	Directly Supports	
Availability of development capabilities in industry	No	Yes	Unavailable	Available	Highly Available	
Availability of development capabilities in-house	No	Yes	Unavailable	Available	Highly Available	
Supporting technology base	No	Yes	Not Developed	Marginally Developed	Well Developed	
Estimated time to complete stages 1 & 2, months ($t_2 > t_1$)			$> t_2$	t_1 to t_2	$< t_1$	
Understanding of technology within DOD			Poorly Understood	Adequately Understood	Well Understood	
Production						
Availability of subsystem & components			Unavailable	Available	Readily Available	Production Performance Related Attributes and MOE_s
Availability of production facilities	No	Yes	Marginal	Adequate	Excellent	
Requirements for special engineering design			Many	Few	None	
Complexity of engineering design			High	Medium	Low	
Estimated time to open production line, months ($M_2 > M_1$)						

EVALUATION AREAS & ASSOCIATED FACTORS	MILESTONE 0		MILESTONE I & II			MILESTONE III
	Program Initiation & Approval for Conceptual Phase		Approval for Validation Demonstration Phase Approval for Full Scale Development Phase			Approval for Production & Deployment
	EVALUATION PROCEDURE: Viability/Justification Checklist		EVALUATION PROCEDURE: Scoring Models			EVALUATION PROCEDURE: Multiattribute-Utility Theory
			Low	Medium	High	
Program Management Structure						
Overall Management	Poor	Good	Marginal	Adequate	Well Qualified	Program Management Attributes and MOE_s
Contracting Staff			Marginal	Adequate	Well Staffed	
Engineering Staff			Marginal	Adequate	Well Staffed	
Program Mangement Plan	Poor	Good	Marginal	Good	Excellent	
Programming of Funds	Infeasible	Feasible				Percentage of Funds Programmed
Production			Not Done	Marginal	Sufficient	
Operational			Not Done	Marginal	Sufficient	
Support			Not Done	Marginal	Sufficient	
Ability of Alternatives to Fulfill Mission Element Need	Improbable	Probable				
Survivability			Poor	Good	Excellent	
Vulnerability			Poor	Good	Excellent	
Other Measures of Effectiveness			Poor	Good	Excellent	

Logistical Supportability	Difficult	Supportable				
Depot Support Activity			Not Available	Marginal	Readily Available	
Availability of Spares			Inadequate	Partial	Full Support	Logistics Supportability Attributes and MOE_s
Complexity of Field Maintenance Required			Very Complex	Limited Complexity	Standard Procedures	
Maintenance Schools			Not Available	Partially Available	Available	
Other						
Standardization	-	-				
Within Service			None	Partial	Complete	Standardization Attributes and MOE_s
Within U.S. Forces			None	Partial	Complete	
Within NATO			None	Partial	Complete	
Environment	-	-				
Ability to Meet International Standards			Inadequate	Partial	Complete	Environmental Protection Attributes and MOE_s
Ability to Meet U.S. Standards			Inadequate	Partial	Complete	
Public Acceptance			Poor	Partial	Very Good	
Energy	-	-				
Measure of Effectiveness #1			Poor Performance	Good Performance	Excellent Performance	Energy Conservation Attributes and MOE_s
Measure of Effectiveness #2			Poor Performance	Good Performance	Excellent Performance	
Other						

EVALUATION AREAS & ASSOCIATED FACTORS	MILESTONE 0 — Program Initiation & Approval for Conceptual Phase — EVALUATION PROCEDURE: Viability/Justification Checklist		MILESTONE I & II — Approval for Validation Demonstration Phase; Approval for Full Scale Development Phase — EVALUATION PROCEDURE: Scoring Models			MILESTONE III — Approval for Production & Deployment — EVALUATION PROCEDURE: Multiattribute-Utility Theory
			Low	Medium	High	
Test Results	-	-				Operational Test Related Attributes & MOE_s
Development Test I			Poor	Good	Excellent	
Development Test II						
Operational Test I			Poor	Good	Excellent	
Operational Test II						
Acquisition Strategy	Not Developed	Developed				
Provides for Competition			None	Some	Much	Acquisition Planning Attributes and MOE_s
Short-term Business Planning			Poor	Good	Excellent	
Long-term Business Planning			Poor	Good	Excellent	
Risk	-	-				Included in Other Factors
Schedule			High	Medium	Low	
Cost			High	Medium	Low	
Technical			High	Medium	Low	
Other						

NOTES: Milestone I & II: (1) Risk is represented by a separate set of factors. (2) The same procedures are used to support both decision processes, however, the overall weight given each evaluation area will change. (3) An evaluation will be necessary for each factor associated with each alternative; Milestone III: (1) Risk is included in the attributes. (2) a Single alternative will be considered for production approval. (3) Attributes and measures of effectiveness (MOE_S) will be developed in each evaluation area. Proxy attributes may be developed.

COMMENT: The validity of the operational requirement documented in the MENS will be examined by use of a checklist prior to decision Milestones I, II, & III.

in relation to each potential program and determine what level of goodness could be achieved. This process would be carried out for all potential programs until a comprehensive checklist of factors has been compiled. These completed checklists would then provide a basis for determining if a particular program met the minimum acceptable standard for approval to advance to the conceptual phase. The checklists would also provide a means for the decision makers to discriminate among the potential programs and establish a priority listing of programs for approval.

Input requirements

The preanalysis effort mentioned above for this task would be effectively accomplished by developing the MENS in accordance with the provisions of the first task. The Unified Program Planning approach would provide the needs, constraints, alterables, and objectives of the problem along with their interrelationships. Brainstorming, the Nominal Group Process, or other means could be used to identify the evaluation areas and their associated factors. The same techniques used for generating ideas could also be used to develop the various levels of goodness associated with each factor.

Table 9 presents a sample list of factors that could be used to evaluate potential systems-acquisition programs. However, this list does not present all appropriate factors but is simply a representative list of the evaluation factors that should be considered. Table 9 shows only two levels of

goodness associated with each factor. Under some conditions, the scale could be broadened to include several levels of goodness. As an example, Bradbury, Gallagher, and Suckling (1973) indicated the following six possible scale levels in relation to viability: no problem, minor and major problems (in relation to performance), minor and major threats (in relation to the availability of solutions), and ignorance (as a measure of uncertainty).

Operational and analysis assumptions

From the operational standpoint of DOD, it is assumed that there is a set of potential programs that must be evaluated. Normally these potential programs would be presented in a MENS. The analysis procedures are not dependent on any strong underlying theortical assumptions for validity of employment. However, it is assumed that meaningful and standardized[2] evaluation areas and factors may be identified. Finally, it is assumed that two or more levels of goodness can be associated with each factor so as to scale that factor.

Location of the analysis effort

The actual analysis effort to support this task could be carried out jointly by the services and OSD. The services could suggest evaluation areas and factors; however, the final structuring of the checklists should be done within OSD.

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[2]Standardized in this case refers to the requirement that the factors identified should be equally applicable to all programs subjected to evaluation.

Role of the decision makers

The top-level managers in the OSD would, of necessity, be involved in developing and filling out the checklists and would make recommendations to the SECDEF on a potential program. This could be done by a simple change in operational procedures without a revision of existing policies. The SECDEF would then make a final determination on the approval of a specific program based on its MENS and the recommendations derived from the checklists.

The role of the systems-engineering teams

The systems-engineering team to be used within OSD would be deeply involved in the initial phases of this analysis task. It would be responsible for coordinating the overall development of the checklist, including the consistency, reliability, and validity of the various evaluation factors. The team would insure that the decision makers were properly educated on the purpose, intent, and employment of the checklists. Once the checklists were fully developed, the team would assist the decision makers in applying them to the evaluation process for the potential programs.

Cost and time considerations

This procedure, which would require a good deal of an analyst's time and dedicated support, is addressed in greater detail in the next section. Initially it would also require some additional time from the decision makers until the

standardized checklists were fully developed. However, once the evaluation process has been fully implemented, the decision makers would not be contributing an excessive amount of time to this decision function. The checklists should complement and amplify the MENS, thereby providing a more concise and well-defined decision package for the top-level OSD managers to consider.

Policy implications

The only significant policy implication associated with this task is the requirement to establish semiannual due dates for the MENS. This requirement could be fulfilled by a revision to DOD directives 5000.1 and 5000.2.

References to the literature for the analysis procedure

The checklist approach suggested here is adapted from the procedure developed by Bradbury, Gallagher, and Suckling (1973). Allen and November (1969), Mickler (1972), Varble (1972), Augood (1973) and Clarke (1974) also wrote about evaluation factors and the development of checklists for the evaluation and selection of R&D programs.

Task #3: To Devleop an Analysis Procedure to Support the DSARC/(S)SARC Decision Process at Major-Decision Milestones I and II

Introduction

This task addresses the development of an analysis procedure that will support the DSARC/(S)SARC decision process at major-decision Milestones I and II. Although there are two distinct decision points to consider, they are quite similar. They both occur during that portion of the overall systems-acquisition process when there is a good deal of risk and uncertainty with the program. This is also the period in the acquisition process when there is a transition from the availability of qualitative to quantitative data.

Another similarity between major Milestones I and II is that the same types of decisions are required to be made at both points. The first decision deals with the evaluation and selection of alternative candidate solutions for advancement to the next phase of the acquisition process. The second decision deals with the go/no-go determination for the overall program to proceed to the next phase.

Because of the similarities between major-decision Milestones I and II, the same type of analysis-support procedures will be used for both.

Relationship to the generalized systems-engineering steps

Considering the systems-engineering-framework analysis of Chapter 3 (p.62), the procedure outlined in this task addresses two of the general steps of the systems-engineering logic dimension. The impact-assessment step is addressed by the structuring of the problem, criteria identification, and program-evaluation efforts associated with this task. The output-specification step is addressed by the decision process for selecting the alternative candidate solutions to proceed to the next phase and making the go/no-go determination for the overall program to advance to the following phase.

Analysis-procedure-selection considerations

Based on the program characteristics, there are three important considerations: availability of data, stage of the acquisition process, and the extent of the resources to be committed to the program. More data are available at these decision points than at the Milestone 0 decision point, but, because of the stage of the acquisition process, much data are still qualitative. The commitment of significant resources is required for a program to advance to the subsequent phase. Consequently the analysis procedures selected to support these decision points must have sufficient depth to justify the commitment of these significant resources. The following organizational considerations are important: how

critical is the decision to the organization, how available is the decision maker's time, and how available is the analysis support. Basically, the significance of the decision should be correlated to the decision maker's time and the analysis support. Because the decisions of Milestones I and II lead to the approval of a system for full-scale development, an exacting analysis procedure is justified to support the decision-making process at these two milestones.

Analysis procedure

The analysis procedure for application in this particular task is that of project-scoring models as addressed by Clarke (1974) and Moore and Baker (1969). Scoring models require decision makers to relate each project's merit to several project characteristics (factors or criteria). Criterion scores can then be aggregated to yield an overall project score. The choice of this approach, with its increased complexity and greater requirement for analysis effort, reflects the greater importance of these decisions to the organizations and the stage of the acquisition process. It also makes the best use of the partially qualitative nature of the available data.

Results and anticipated benefits

This analysis procedure should produce:

1. A preference for which of the alternative candidate solutions should be advanced to the next phase.

2. A determination of whether or not the overall program should be advanced to the next state (phase).

This procedure would enhance the ability to discriminate among the various alternative candidate solutions and between the merits of approving or not approving the overall program for advancement to the next phase.

Capsule description of the analysis procedure

Several phases are required to develop the project scores. First, the Unified Program Planning (p.192) could be used in a preanalysis phase to identify and define the decision situation. Next, an optional preparatory phase would be required in which the project score forms would be developed, if necessary. Table 9 shows several suggested evaluation areas and associated factors to be identified although it is not a comprehensive listing. As many as five to seven scale values could then be developed for each factor.

The next phase would determine the factor weights within each evaluation area. Here, each individual decision maker would rank the factors in each evaluation area; each factor could then be converted to a numerical value assuming equal intervals between adjacent ranks. Group evaluations could be calculated by averaging the set of numerical weights, assuming that each decision maker had an equal degree of knowledge. The list of factors with their associated weights and scaling values would make up the overall project score sheet (Table 9).

The final phase of the analysis procedure would be to evaluate each project or alternative at each decision point. First, the decision makers should concur on the value assigned to each evaluation factor associated with each project or alternative. A score could then be developed for each evaluation area by multiplying the factor weight by the corresponding value and then adding all factors. Total project scores would be obtained by summing the evaluation areas. The decision makers could assign a decision variable for the risk, r, that could be introduced into the problem; this would premultiply each evaluation area score. Higher values of r would indicate less risk for that particular evaluation area and lower values, greater risk.

A mathematical representation of the scoring model is presented as follows:

$$S_i = \sum_j r_j \left(\sum_k w_{jk} v_{ijk}\right)$$

where S_i is the total score for the i^{th} project; r_j is the risk factor for the j^{th} evaluation area (all values of r_j would sum to one); w_{jk} is the weight of the k^{th} factor in the j^{th} evaluation area; and v_{ijk} is the scaling value for the k factor in the j^{th} evaluation area for the i^{th} project.

The procedure described above could be directly applied to the types of decisions used for evaluating and selecting alternative candidates to be advanced to the next phase. However, the evaluation factors would require some

revision from the Milestone I decision problem to the Milestone II decision problem.

A procedure to support a decision for a go/no-go determination for an overall program to advance to the next phase would also require preanalysis. Initially, a group of decision makers must determine a baseline subset of factors and associated scaling values to be used to establish the minimum acceptable standard score to advance the overall program to the next phase. The factors chosen and the standard score would then be used to gauge the probability of success of the program in the next acquisition phase. As more programs are subjected to this analysis procedure, the factors necessary to calculate success probability would become more readily identifiable. The minimum standard score necessary to forecast a reasonable degree of future success would also become more visible. An optimum set of baseline factors and the minimum standard score to project the success of the program, within some reasonable limits, could then be selected.

Input requirements

The preanalysis phase mentioned above would be effectively accomplished by using the Unified Program Planning approach. With this approach the MENS could be updated to properly define the system-development problem under consideration. The evaluation areas, evaluation factors, and scaling values associated with each factor would have to be developed;

the Nominal Group Process, or another means of generating ideas, could be used to develop the evaluation factors and the various scaling levels. Table 9 presents a representative list of evaluation factors and scaling level-terms applicable to Defense systems acquisitions.

Operational and analysis assumptions

From the operational standpoint of DOD, it is assumed that a set of alternative candidate solutions associated with a specific acquisition program requires evaluation to determine that should be advanced to the next acquisition phase. It is also assumed that a go/no-go determination must be made on whether the overall acquisition program should proceed to the next phase.

The analysis procedures to develop the project scores assume a linear model. Therefore, the projects are ranked on an ordinal scale and there is no way to determine how much better one project is than another. In identifying and using the evaluation factors, it is assumed that they are mutually exclusive and score independently.

Since the project score is a single performance measure, there is no way to gain a utility measure of the various projects using the scoring model (Dean and Nishry, 1965). Finally, the scoring model will not effectively reflect the risk associated with these stages of the acquisition process except through the introduction of a

decision variable for the risk factor, r, as discussed above.

Location of the analysis effort

The actual evaluation of the alternative candidate solutions would begin in the systems-program offices. These program offices, and other service elements, could assist in identifying and developing the evaluation areas and factors. The systems-program offices could use the analysis procedure noted above to arrive at their initial recommendation on which alternative candidate solutions are to enter the next phase. However, to support the DSARC and (S)SARCs decision processes, much of the analysis for this task would have to be carried out within OSD and at the several service headquarters, respectively. These councils should at least validate the recommendation and make their own decisions on the go/no-go determination for the overall program. Therefore, the structuring of the decision problem, the final development of the project scoring sheets, and the actual use of the scoring models would have to be accomplished within OSD and the several headquarters elements.

The role of the decision makers

As indicated above in the description of the analysis procedure, the members of the DSARC and the (S)SARCs would be involved in several phases of the analysis effort. Initially, they would need to be educated in the overall procedure; then

they should be involved in identifying and developing the evaluation areas and factors. Finally, they would have to evaluate the alternative candidate solutions and the overall programs.

The role of the systems-engineering teams

The systems-engineering teams recommended for OSD and the several service headquarters would be deeply involved in supporting this procedure throughout its use. Initially, the team members would have to educate their decision makers (the DSARC/(S)SARC members) in the purpose, intent, and employment of the procedure. They would have to insure that the general systems-engineering step of input description and specification used the Unified Program Planning approach. The team members should coordinate the development of the evaluation areas, the factors, and the associated scaling values for the factors. Finally, the analysts should assist the decision makers in using the scoring models.

Cost and time considerations

This procedure would require a good deal of an analyst's time and associated funding support. Initially, the decision makers would need time to familiarize themselves with the procedure and to develop the evaluation areas, factors, and scaling values associated with the factors. However, once the evaluation process is fully implemented, the decision makers would only need to evaluate and select the alternative

candidate solutions and make the go/no-go determinations for the programs. This function could be accomplished in approximately the same time that is now devoted to the evaluation and selection process.

Policy implications

No policy revisions would be necessary to implement this analysis procedure. Only certain procedures in the decision process would need revision.

References to the literature for the analysis procedure

The capsule description of the analysis procedure is partially adapted from Dean and Nishry (1965). Baker and Pound (1964), Pound (1964), and Moore and Baker (1969) all addressed the development and employment of scoring models. Augood (1973), Baker (1974), Clarke (1974), and Baker and Freeland (1975) all assessed the use of scoring models for evaluating and selecting R&D projects. These latter authors also presented scoring models in the context of the overall set of project evaluation and selection techniques.

Task #4: To Develop an Analysis Procedure to Support the DSARC/(S)SARC Decision Process at Major-Decision Milestone III

Introduction

This task develops an analysis procedure to support DSARC/(S)SARC decision process at major-decision Milestone III.

Only one type of decision needs to be made at this milestone--the go/no-go determination for the overall program to advance to the next phase.

The decision at this milestone is whether to produce and deploy the system. During the previous acquisition phase, the service responsible should have fully developed the single alternative candidate solution that would now be considered for production. Risk should, therefore, be at its lowest point and the number of evaluation factors should be reduced as there are no alternative candidates involved. However, the commitment of resources will be high for both the production and operational deployment phases.

Relationship to the generalized systems-engineering steps

Considering the systems-engineering-framework analysis of Chapter 3, the procedure outlined in this task addresses the generalized step of output specification and interpretation. This is because the decision under consideration is a go/no-go determination. However, the previous steps in the systems-engineering logic dimension must be carried out to provide a foundation and framework for this particular decision.

Analysis-procedure selection considerations

Based on the program characteristics, important considerations are the stage of the program and the extent

of the resources to be committed to the program. At this milestone, a great deal of quantitative data should be available to support analysis and the resource commitment is large and should be complemented with a thorough analysis.

Considering this major-decision milestone from an organizational standpoint, this decision is critical to the service involved and to the DOD. It decides some subsets of the next generation of Defense systems. Therefore, it *must* be as carefully analyzed as possible in accordance with the availability of decision makers' and analysts' time.

Analysis procedure

Decision analysis, as outlined by Sage, Warfield, Thissen, et al. (1978), has been selected for this particular task specifically, the use of multiattribute utility theory. This approach will insure the greatest value from using the evaluation factors presented in Table 9. The critical decision situation necessitates the rigorous analysis procedure of the multiattribute utility theory. This procedure will require a good deal of time from both the decision makers and the analysts, which is justifiable when the magnitude of the commitment of resources needed for production and the importance of the decision to deploy the system are considered.

Results and anticipated benefits

This analysis should produce:

1. A model, usually a decision tree, to represent the actual situation at major-decision Milestone III.

2. An optimal course of action, so that the decision makers (the DSARC/(S)SARC members) know whether or not to produce the system based on their own utility functions.

3. An analysis of the sensitivity of the best course of action to errors in the data.

This procedure would enhance the ability of the decision makers to discriminate between the decision alternatives of going or not going to the production and deployment of the system. This would also enable the decision makers to discern the probability of success of the system during production and deployment.

Capsule description of the
analysis procedure

The description below has been abstracted from the "Research Concerning a User's Guide to Public Systems Methodology", by Sage, Warfield, Thissen, et. al. (1978).

> Several steps or phases are involved in conducting a decision analysis and are proceeded through in an iterative manner. A *pre-analysis effort* is directed toward identifying and defining the decision situation. Activities include identifying needs, pertinent constraints, alterable quantities, and objectives. The input specification portion of a system effort yields this information. A *structuring effort* is directed toward identifying decisions and outcomes and the relationships between them, and structuring preferences to facilitate evaluation of outcomes. This is accomplished in the impact assessment step. Encoding of information pertaining to the uncertainty of outcomes and incorporating decision maker attitude toward

risk into a function describing the decision maker's preferences are the principal tasks in a *probabilistic effort.* In an *informational effort,* the impact of additional information to resolve uncertainty on the outcomes or by a reiteration through some or all steps is assessed. An optimal strategy is then calculated for the decision maker to follow, and subsequently, the decision is made.

This procedure may be extended to incorporate the input of several decision makers and a variety of different evaluation factors or attributes. In this context, *attribute* may be defined as the characteristic or quality that will indicate the degree to which a systems-acquisition program under consideration meets the development objective with which the attribute is associated. When there are several decision makers, as is the case in the DSARC/(S)SARC decision process, and there are a number of attributes, then the decision becomes a group decision and multiattribute utility theory is applicable. This analysis procedure responds to the complex and uncertain nature of the decision situation at Milestone III.

Input requirements

Implementation of the decision-analysis procedure would require several inputs. First, the decision makers and the analysts would jointly have to:

1. Define the decision situation by using the Unified Program Planning. The needs, constraints, objectives (and their structure), and the measures for evaluating their achievement should be included.

2. List the alternatives available to the decision maker from which one, and only one, must be selected at the completion of the analysis. In this case, the alternatives are simply the go or no-go determinations to produce and deploy.

3. List the possible outcomes of which one, and only one, is possible after a decision is made. In the case of the systems-acquisition process, these outcomes are the success or failure of the system during production and deployment.

4. List the attributes associated with the development objectives for the decision situation. These attributes would be analogous to the evaluation factors presented in Table 9.

The decision makers, with the assistance and guidance of the analysts, should also:

1. Answer questions about the relationship between the alternatives and the outcomes.

2. Answer questions about the likelihood of the occurrence of each outcome based on the information available.

3. Answer questions about the value of the outcomes.

4. Answer questions about preferences for outcomes in uncertain situations so that attitudes concerning risk can be identified.

Operational and analysis assumptions

From the operational standpoint of DOD, it is assumed that development programs moving through the acquisition process must be evaluated by a group of decision makers (DSARC/(S)SARC members) to ascertain whether or not they should proceed to production. The assumptions, on which this analysis procedure is based, were developed by Sage, Warfield, and Thissen, *et al.* (1978):

> It is assumed that the decision maker's alternatives and the possible outcomes of those alternatives can be identified. It is also assumed that the decision maker (through personal knowledge, that of experts, and/or stakeholders) has some knowledge about the relationships between alternatives and outcomes, and that the reality of the decision situation can be captured in a model. In quantifying decision maker preferences, the position is rejected that the decision maker's preferences can only be revealed through actions already taken. That is, decision analysts operate under the assumption that the decision maker has the ability to express preferences for outcomes.

Location of the analysis effort

The actual evaluation of the systems-acquisition programs should begin in the systems-program offices. These offices could do much of the preanalysis. However, the bulk of the analysis would have to be carried out within OSD and at the service headquarters because the decision makers (the DSARC/(S)SARC members) would have to work closely with the analysts (the members of the systems-engineering teams) to carry out the decision-analysis procedure.

The role of the decision makers

As indicated above in the description of the analysis procedure, the members of the DSARC and the (S)SARCs would be deeply involved in several phases of the analysis effort. They would have to work closely with the analysts to structure the decision problem and to determine the decision alternatives for and outcomes of the problem. They would also have to supply the analysts with a variety of answers to questions about the relationship of alternatives to outcomes, the probability of the occurrence of outcomes, and the value to the decision makers of the various outcomes. The DSARC/(S)SARC members should have sufficient educational background, managerial experience, and R&D knowledge to contribute effectively to the decision-analysis procedures.

The role of the systems-engineering teams

The systems-engineering teams projected for OSD and the several service headquarters would support this procedure throughout its implementation and utilization. Initially, the team members would have to educate the decision makers (the SDARC/(S)SARC members) in the purpose, intent, and employment of the procedure. They would also have to insure that the systems-engineering logic steps are properly carried out before the decision step. Finally, as indicated previously, the team members (analysts) would have to work closely with

the decision makers in structuring the decision problem and analyzing the optimal course of action.

Cost and time considerations

The initial implementation of this analysis procedure would require time from both analysts and decision makers because the decision situation would have to be structured in detail so that both analysts and decision makers would clearly understand the problem. Much of this problem structuring would not have to be repeated each time a program was evaluated. However, the use of this analysis procedure would still require more time from decision makers than is currently being devoted to these types of decisions. The improvement in the decision-making capability should compensate for the additional time required of the decision makers.

Policy implications

No policy revisions would be necessary to implement this analysis procedure. The implementation would require only that certain procedures in a decision process be revised.

References to the literature for the analysis procedure

Sage, Warfield, Thissen, *et al.* (1978) presented an overview of this analysis procedure. Raiffa (1968) wrote a basic text for decision analysis; multiattribute utility theory is

addressed in depth by Keeney and Raiffa (1976); and Sage (1977) covered a variety of topics related to decision analysis. The *IEEE Transactions on Systems, Man and Cybernetics* presented a "Special Issue on Behavioral Decisionmaking" (1977). Litchfield, Hansen, and Beck (1976) suggested using a decision-analysis model in the R&D environment and Keefer (1978) also addressed the use of a decision-analysis model to allocation planning for R&D with uncertainty and multiple objectives. Roesch (1977) applied decision analysis to a project evaluation-and-selection problem of the Defense systems-acquisition process.

In the context of the DOD environment, much of the analysis effort described above would be accomplished prior to and outside of the formal DSARC/(S)SARC proceedings. However, the results of the analysis efforts would be used during the formal DSARC/(S)SARC proceedings to support the formal decision process. The decisions, which resulted from the proceedings, would be documented in the DCP. This decision vehicle would then be processed in accordance with the procedures previously discussed. Some portion of the analysis supporting each decision would be included in the DCP when it was forwarded to higher authority.

The several analysis tasks outlined above are not a comprehensive set of tasks that could be applied to support the systems-acquisition decision process. Rather, these tasks are representative of the types of analysis procedures that could be applied to support the decision process.

Implementation of the Methodology

The analysis procedures which constitute the systems-engineering methodology for the Defense systems-acquisition process are outlined in the previous section. These analysis procedures, or others that could be developed at a future date, are of little value unless they are effectively implemented. A number of papers on this topic were included in the work edited by Schultz and Sleven (1975). Huysmans (1970) specifically addressed the introduction of operations research methods into organizations to assist with management-related decisions.

This section addresses the general area of implementation, specifically, the implementation of the methodology developed in the previous section. The following topics are discussed: The consideration of a major barrier to effective implementation, a recommendation for the formation of a systems-engineering (multidisciplinary) team to minimize this barrier and to implement the methodology, and the identification of general characteristics and functions of the team. The functions needed for the systems-engineering team to implement the methodology in the DOD environment are listed. Finally, the means for measuring the effectiveness of the systems-engineering methodology once it is implemented will be evaluated.

Many problems could inhibit an analysis procedure from being effectively used to assist in the policy and

decision-making processes. Several of these inhibiting factors are the lack of quantifiable information available on which to base decisions, the *unique* nature of the organization of problems, and the lack of resources for analysis efforts, including qualified personnel. However, in the author's opinion, the major barrier to using analysis procedures for establishing policies and making decisions is the separation between the managers and the analysts within an organization. In many cases, their activities and functions do not interrelate. They may not be motivated toward common goals, and the communication between the two groups is poor at best (Rosenzweig, 1967).

An example can be drawn from the section on *The Criteria and Organizational Considerations for Applying the Systems-Engineering Tools and Techniques* (p. 167) to illustrates the problem. If only criteria for the acquisition-program characteristics had been selected, then the environment in which the analysis takes place could have been ignored. Many management scientists and operations analysts would find nothing at all odd about this. However, the environment of the analysis is the organization, which must plan for, pay for, carry out, and will, hopefully, benefit from the analysis.

Why then would analysts view the analysis situation from the narrow contest of what is to be modelled versus the larger prospective of the organization and its goals. This question, which was addressed in some detail by Kast and

Rosenzweig (1974), among others, is closely related to the behavioral aspects of decision making. These authors effectively described the problems associated with the separation that exists in some organizations between policy makers and decision makers and the analysts.

Several suggestions are offered as to why the problems exist. First, as a student, an analyst is taught algorithmic approaches that are presented by class and type. Normally, the student is led to anticipate a particular type of problem and is not usually called on to select the appropriate analysis approach, let alone to visualize it in an organizational context. Second, when an analyst joins industry, commerce, or government, the opportunity seldom arises to look at the decision problem from the manager's standpoint. An analyst works in a rather cloistered environment at low levels of the organization where decisions are simply regarded as problems to be modelled and then analyzed by various techniques. This prospective is restrictive, causing the analyst to omit significant factors when modelling the decision situation and leading to difficulties in communicating plans, procedures, and results to decision makers and policy makers.

On the other hand, the decision maker or policy maker generally has a broader, more varied education with less formal training in analysis and quantitative methods. Additionally, the professional experience gained in the upper echelons of industry, commerce, or government is broader than

that of the analyst. These people view a major decision as a multidimensional problem with possible political, economic, environmental, and societal impacts. The decision and policy makers' lack of a strong background in quantatitive methods and their larger prospective of the decision problems impede communication with the analyst regarding analysis plans, procedures, and results. Therefore, the decision makers and policy makers fail to obtain the full value of the analysis efforts within their organizations.

In summary, an artificial gap exists between the decision makers and policy makers and the analysts (management scientists, operations analysts, etc.) within many organizations. This gap needs to be bridged if managers are to gain the greatest possible benefits from analyses.

A systems-engineering (multidisciplinary) team could minimize this gap. The formation of such a team is the first step toward bringing the capabilities of the systems engineer to bear on the problem. Hall (1962) outlined the qualities that a systems engineer should possess as follows:

1. Demonstrated (not merely professed) affinity to the systems point of view.
2. Faculty of objective judgment and sound appraisal.
3. Imagination and creativity.
4. Facility in human relations.
5. Effectiveness as a broker of information.

Gibson (1977) described the systems team with subject-area specialists as having a goal, a leader, a methodology, and a schedule. Gibson stated, "Subject-area knowledge is

necessary, but not sufficient for a successful system study." He pointed out that, in some instances, in-depth knowledge is necessary to study certain key issues. Several different multiple disciplines must be represented in a team so that it may implement its analysis confidently and aggressively recommend the products of these analysis efforts to management. The multidisciplinary aspects of the team are also particularly important to the team's information brokerage role.

The need for systems-engineering teams in R&D is effectively stated by Gibson (1979). These teams could be employed in R&D by assisting in the analysis required to carry out the several steps and phases of the systems-engineering methodology. The systems engineer and his team could also act as translators for the analyst and the decision maker or policy maker. Shakum (1972) cited the need for managers at all levels to have a closer relationship with and a better understanding of the analysts within their organization.

The systems-engineering team is suggested as a means by which to directly pursue these goals. The team contemplated here and more fully described below has its most meaningful role in large, complex organizations. These organizations generally have a major headquarters where policies are formulated and a variety of locations where analysis is carried out. The systems-engineering team envisioned here would normally be located at the headquarters.

Many MS/OR (management science/operations research) analysts, engineers, and scientists are neither well equipped nor motivated to interrelate effectively with managers, neither are managers inclined to seek out the analysts. The members of a systems-engineering team can come from either group but should feel comfortable with both. Figure 31 shows the role of a headquarters-located, systems-engineering team in addressing decision problems. This figure shows multiple MS/OR groups and other engineering and scientific analysts at different locations. The decision makers and policy makers and the analysts have their own and differing views of the decision problems; the analysts work directly with the analysis models while the decision makers and policy makers view them only from a distance.

The systems-engineering team operates with both the decision makers and policy makers and the analysts to draw out issues, questions, and answers. Its primary role is *to bridge the gap* between both groups. The team should not inhibit communications between the two groups but enhance communications by translating in both directions and for each group. The team acts as an information broker, as a mediator of technical matters, as an interpreter of analysis efforts, and as a synthesizer of management guidance. The need for this team becomes even more critical when, as indicated in Figure 31, there are several analysis groups at separate locations.

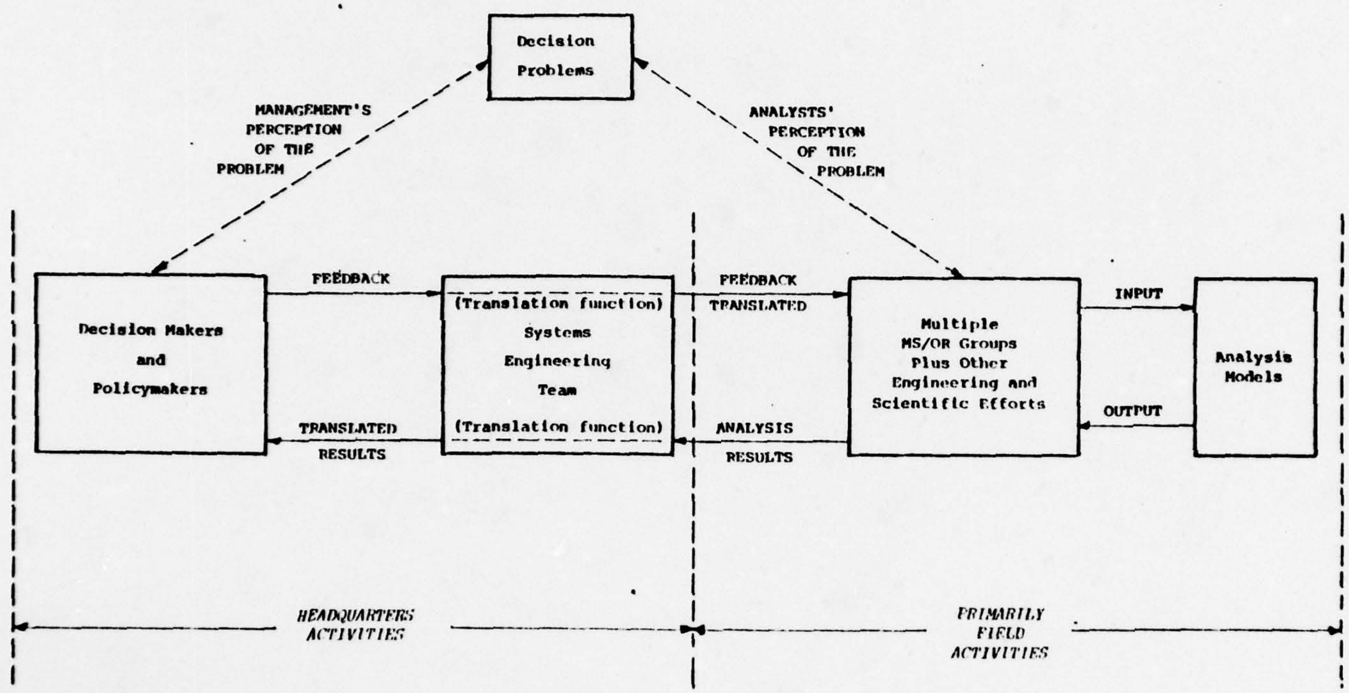

Figure 31. The Role of the Systems-Engineering Team in Addressing Decision Problems within Large and Complex Organizations.

A systems-engineering team must have several distinctive characteristics if it is *to bridge the gap* effectively. Each member of the team should possess these characteristics particularly, the leader or manager of the team.

Characteristics of the Systems-Engineering Team

Multidisciplined

The team should include several different disciplines, including MS/OR or computer science, engineering, and others as required. Each member should be trained in more than one discipline.

Well Educated

Most members of the team should have graduate-level educations with particular emphasis on quantitative analyses. A strong technical background will allow the team members to be involved in the wide-ranging technical discussions, briefings, and studies necessary to perform their responsibilities. It also enables the systems engineer to filter out comments and information that are not pertinent to the central theme of a particular problem or analysis effort.

Mature and Experienced as Analysts

The members of the team should have served an analysis apprenticeship and now have *moved up* to a systems-engineering position. Previous experience on a variety of programs should be a prerequisite for joining the systems-engineering team.

Experienced in Operations or Management

Members of the team should have previous management experience that enables them to better grasp the decision maker or policy maker's perspective on the problem. Operational experience in a field activity will provide greater insight into the real-world aspects of the decision problem under consideration.

Outgoing in Professional Relationships

The members of the systems-engineering team need to actively seek out contacts and interactions with both the management and analysis groups; special insight and understanding into the problems of both groups is needed. This type of in-depth perception can only be gained by close personal contacts.

Trustworthy

The members of the systems-engineering team should be sincere and honest in their relationships with managers and analysts. Trust by both groups will motivate each group to be as cooperative as possible. So that the members of the team have no vested interest in any particular program, they should be full-time employees of the organization. External consultants should have an exclusion clause in their contract for all aspects of the acquisition program, except those dealing with analysis.

Innovative

The systems-engineering team should be innovative and creative in their thinking and view problems in a holistic fashion. They should have the ability to conceptualize the structure and nature of problems with only limited guidance from a decision maker, client, or sponsor.

The size of the team is also important but it is difficult to say what the overall size of a team at a major organizational headquarters should be. However, when a specific team is formed to address a particular problem (for instance, the consideration of a major R&D program), then the team should include approximately four to seven professional members with appropriate administrative and technical support. If the team is any smaller, the required disciplines would not be represented; if the team is larger, it becomes unwieldy and less productive.

A systems-engineering team, attempting *to bridge the gap* between the management and analysts group, should perform the functions outlined below:

General Functions of the Systems-Engineering Team

1. To be cognizant of ongoing analysis efforts within the organization. This requirement is particularly important as it concerns large R&D programs prior to major-decision milestones.

2. To monitor and assist in the implementation of standardized analysis procedures directed by organizational policies. This does not mean being responsible for the implementation efforts but for being aware of how they are proceeding.

3. To advise management on overall analysis policies. If the organization has analysis efforts being carried out in a variety of locations, analysis policies could be standardized.

4. To keep the analysis groups informed of policy revisions that could impact analysis procedures.

5. To translate the results of internal analysis efforts into management information. In many cases, the products of the analysis groups should be translated for management so that full value may be gained from the analyses.

6. To interpret the results of other organizations' analyses for management. Sometimes analysis efforts external to the organization must be evaluated. The teams should then provide management with concise and valid assessments of the impact and meaning of the external analysis efforts.

7. To be an advocate of the systems-engineering approach and analysis. This does not mean to be a proponent of a particular alternative or algorithm but it does mean to be positive in discussing the merits of systems engineering and its tools and techniques.

8. To educate management to the value and proper use of analysis procedures.

9. To carry out critical analysis procedures that have major policy- or decision-making significance to the organization. On an infrequent basis, the top-level management of the organization may require that the systems-engineering team to analyze a problem. Typically this would be to gain a parity check on an analysis performed outside the organization that could be time sensitive or highly visible in its impact. This is basically a misuse of a team's capabilites but may be directed by top-level management; it can gain a great deal of good will within the organization.

The functions described above are general and applicable to a systems-engineering team trying *to bridge the gap* at the headquarters of any large, complex organization. These functions could, therefore, be applied to systems-engineering teams operating within the DOD. Specific functions that these teams could perform in implementing the systems-engineering methodology on the service-headquarters level and within OSD are outlined below.

Specific Systems-Engineering Team Functions Within OSD

1. To assist OSD in developing an overall systems-acquisition-analysis policy for DOD. An example would be the development of the methodology outlined in the previous section.

2. To assist service headquarters in implementing systems-acquisitions-analysis policies and methodologies to insure uniformity in implementing the procedures of the methodology.

3. To assist the service headquarters in preparing for specific DSARC major-decision milestones.

4. To assist in the education of the DSARC members in the theory, procedures, and practices of the systems-engineering methodology.

5. To assist in the development of the actual analysis structure for the DSARC program evaluation, selection, and approval. This should include identifying the criteria and factors necessary for an evaluation of the candidate system alternatives and the overall program. Assisting DSARC members in developing their own value and utility functions to evaluate the program could also be included.

6. To assist the DSARC members in carrying out the actual trade offs involved in evaluating the major systems-acquisition programs, including how various operational policy matters could be revised as a function of the acquisition of new Defense systems.

Specific Functions of the Systems-Engineering Team Within Service Headquarters

1. To assist the system-program offices and subordinate commands in implementing the system-engineering methodology for systems acquisition.

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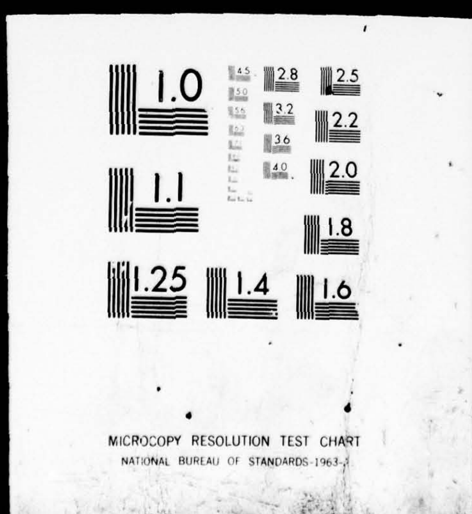

2. To assist the systems-program offices in preparing for specific (S)SARC major-decision milestones.

3. To assist in educating the (S)SARC members in the theory, procedures, and practices of the systems-engineering methodology.

4. To assist in developing the actual analysis structure for the (S)SARC program evaluation, selection, and approval.

5. To assist the (S)SARC members in carrying out the actual trade offs involved in evaluating the major systems-acquisition programs.

The systems-engineering teams described above are not required in every organization or at every level of activity. However, as previously indicated, these teams may be effectively employed at the headquarters of large, complex organizations that have multiple-analysis activities at various locations. In the context of the DOD environment, systems-engineering teams should be established within OSD and within the several service headquarters. All these locations are the headquarters of large, complex organizations with multiple-analysis activities at several lower echelons and at a variety of locations. Figure 32 graphically depicts the location of the several suggested systems-engineering teams in the DOD environment. The Marine Corps does not normally have systems-program offices *per se* but it does have subordinate commands

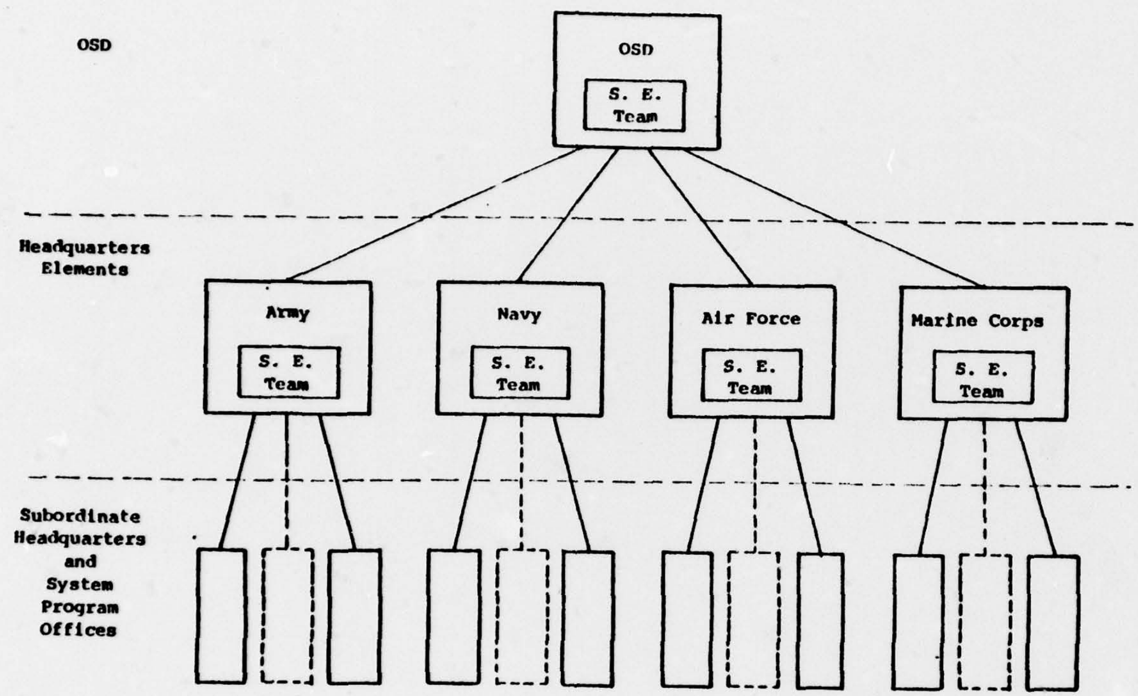

Figure 32. Locations of Systems-Engineering Teams Within DOD to Support the DSARC/(S)SARC Process.

that analyze systems acquisitions and it does use the capabilities of the other services' systems-program offices.

Each of the service headquarters and OSD have major staff sections primarily concerned with research, development, and acquisition. The systems-engineering teams could be located in these major staff sections. To insure communication between the team and the policymakers or decision makers, the manager of the systems-engineering team should report directly to the senior official managing the staff section.

Redundancy, feasibility, and validity of requirement are questioned when the suggestion is made to establish yet another analysis unit. However, there is no current standardized DOD systems-engineering methodology to assist in the decision process for major systems acquisition. In addition, no analysis unit in the several locations noted above is performing the full set of functions described for the systems-engineering teams. Therefore, such teams would not contribute to the redundancy of functions.

The current research should substantiate the validity of systems-engineering teams of the type described above. The work on the structuring of the systems-acquisition process and the development of the methodology show the possibilities of applying systems engineering to the overall program. Those familiar with the problems of communications

between managers and analysts should also see the benefit of the functions outlined for the systems-engineering team.

The question of feasibility is best addressed by considering the activities of the Headquarters Department of the Army. The Directorate of Systems, Review and Analysis, within the Office of the Deputy Chief of Staff for Research, Development, and Acquisitions, Headquarters Department of the Army performs some functions that are slightly similar to those of the systems-engineering team (Army, 1978b). In addition, the Headquarters Department of the Army has provided for independent evaluation teams to consider specific problem areas relative to its Army SARC major-decision milestone points. These independent evaluation teams will develop new information, "determine counter-arguments," and "anticipate specific criticisms from sources outside the Army" (Army, 1978b). Based on these comments, it appears that one of the services has already considered implementing certain functions that are, at least, peripheral to those suggested for the systems-engineering team. The responsibilities of the Office of the Assistant Secretary of Defense (Program Analyses and Evaluation) could also include those outlined for the systems-engineering teams. Therefore, implementation of the systems-engineering team approach should be viewed as being feasible since preliminary activities are already operating within DOD.

The cost of implementing the systems-engineering methodology and the systems-engineering teams would be minimal. Some slight revisions in the policy dealing with systems acquisitions and a number of procedural changes would be necessary. But, the actual funding required would be primarily in the area of the qualified systems-engineering personnel and the necessary technical and administrative support. Smaller systems-engineering teams of four to seven members could address a specific systems-acquisition program as it approached a major-decision milestone. Normally only four or five programs would require close analysis at any one time. Therefore, an overall systems-engineering team of approximately twenty-five people at each of the major headquarters could implement the methodology and perform the functions previously outlined.

Effectiveness Measures for Evaluating the Benefits of Implementing the Systems-Engineering Methodology

The final topic of this section covers the following measures of effectiveness for evaluating the benefits of implementing the methodology and forming the systems-engineering teams.

1. The number of MENS developed, processed, and approved for active programs should increase. If the requirements for the MENS are more clearly defined, then they will be more readily completed. This will enable all programs to be on equal footing, thereby insuring a greater degree of equity in the evaluation and selection process.

2. The number of areas where operational requirements are ambiguous should be reduced. More clearly defined MENS should result from implementation of the methodology and its problem-definition aspects. More clearly defined problem statements should reduce areas of conflict between and duplication of requirements.

3. The overall projected funding for the completion of all programs should be reduced. The absolute number of programs should be reduced with the introduction of procedures to trade off the various programs early in the acquisition process. This reduction should also lead to a reduction in projected overall funding.

4. The variance among the conditions of programs appearing before the DSARC/(S)SARC should be reduced. The methodology will identify key evaluation factors critical to each state of the decision process. The highlighting of these factors should lead to more consistent program performance. For example, this variance could be measured at the production-decision milestones by measuring the number of Engineering Change Proposals per million dollars of production effort for each program. Another quantifiable measure of this variance in the logistical support area is the number of new supply-line items introduced to the overall inventory per million dollars of production effort for each program.

5. The number of programs failing or requiring major revisions in the phase *after* a specific decision point should be reduced. As the methodology is implemented and improved, a greater consistency will develop between program approval and program performance. As the methodology evolves, the decision makers should be better able to determine which key evaluation factors are the best predictors of future program performance. This would, of course, be a long-range means of evaluating the programs and the implementation of the methodology.

Summary and Conclusions

This chapter discussed the various aspects of developing a systems-engineering methodology for Defense systems acquisition. The methodology is designed to support the DSARC/(S)SARC decision process through systems engineering. The methodology is specifically directed toward providing analysis support for major-decision Milestones 0, I, II, and III of the systems-acquisition process.

Initially, the existing procedures associated with the decision process and value system operative within the DSARC and several (S)SARCs were examined. The nature and structure of the Defense systems-acquisition process were then investigated. The criteria and organizational considerations for applying the systems-engineering tools and techniques were identified. Next, the appropriate emphasis of the methodology was considered. This resulted in identifying several areas

where the systems-engineering analysis would best support the DSARC/(S)SARC decision process. The specific analysis procedures to be used in the methodology were then outlined and associated with each of the decision-process support areas previously identified. Finally, various methodology implementation considerations were discussed. This section included a discussion of the motivation for and the functions and characteristics of several systems-engineering teams projected to support the implementation of the methodology.

Based on the material developed in this chapter, the following conclusions are drawn:

1. That there is a perceptible value system operative within the OSD and the several service headquarters relative to the Defense systems-acquisition decision process.

2. That a study of the policies and procedures associated with the systems-acquisition process leads to the following significant observations:

a. That the MENS development phase is, in reality, the problem-definition step of the systems-acquisition process and, as such, is critical to the overall analysis effort.

b. That it is important to consider possible means by which the candidate programs, as represented by the MENS, could be traded off early in the systems-acquisition process.

c. That the decisions required at each major-decision milestones are different in their nature, intent, and impact.

3. That the systems-acquisition process may be modelled as a *stage approach* problem with normally decreasing uncertainty, increasing fund requirements, and increasing availability of reliable, quantitative data as the process advances from phase to phase (or stage to stage).

4. That organizational considerations are important in determining the type, nature, and degree of the analysis effort to be applied within a systems-engineering methodology.

5. That the following areas associated with the DSARC/(S)SARC decision process could benefit by analysis within a systems-engineering methodology:

a. The establishment of procedures for developing a MENS that would more clearly define the operational-requirements problems and make its characteristics more identifiable.

b. The evaluation procedure by which the programs, as represented by the MENS, might be traded off early in the acquisition cycle.

c. The analysis procedures which support the DSARC/(S)SARC decision process at major-decision Milestones I, II, and III.

6. That the several analysis procedures outlined as tasks for the methodology are general steps or specific phases within the systems-engineering morphology.

7. That the effective implementation of the methodology could be significantly enhanced by the formation and proper use of systems-engineering teams working with top-level managers within OSD and the several service headquarters.

The analysis procedures previously outlined as tasks within the systems-engineering methodology do not represent a comprehensive application of all possible systems-engineering tools and techniques to support the systems-acquisition decision process. Rather, the analysis tasks are representative of the type of systems-engineering support that could be provided to the decision process. Further research into the decision process should identify other areas where additional systems-engineering tools and techniques could be beneficially applied.

The next chapter presents a real-world example of the application of the systems-engineering approach to a Defense systems-acquisition problem. This example specifically adresses the formation and use of a systems-engineering team trying *to bridge the gap* discussed in the *Implementation of the Methodology* section of this chapter.

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Chapter 5

RESEARCH INTO AN APPLIED SYSTEMS-ACQUISITION PROBLEM

Introduction

A strategy has been documented in previous chapters for using the systems-engineering methodology to support the Defense systems-acquisition decision process. The need for systems-engineering teams to assist in implementing the methodology has been documented and the functions and characteristics associated with these teams have been outlined. The specific methodology outlined, or other possible approaches, would be most effectively implemented by developing and properly using the suggested systems-engineering teams. To demonstrate this, an applied problem is investigated from a historical perspective. Specifically, a Defense systems-acquisition program is examined to see what impact the employment of a systems-engineering team and approach would have on the development effort.

The DOD development effort selected for examination is a joint systems-acquisition program between the Air Force and the Marine Corps. The overall program is oriented toward developing a computer-based system for the processing of tactical intelligence and was outlined in an Air Force systems command document (Air Force, 1978). Specific Marine Corps involvement in the program was directed by *Marine/Air Ground*

Intelligence System (MAGIS) (Navy, 1978). An overview of how the system should operate in an operational environment was presented by Layne and Jorgenson (1974).

The overall DOD name and the Air Force's specific name for the system is the Tactical Information Processing and Interpretation (TIPI) System; the Marine Corps calls it the Marine Air/Ground Intelligence System (MAGIS). MAGIS consists of several subsystems, or segments, which are addressed in:

1. *R&D Status Report and Program Schedule, TIPI System Integration and Checkout Contract*, (GE, 1979).

2. *Marine Air/Ground Intelligence System (MAGIS) Development and Operational Concepts*, (Navy, 1973c).

3. *Systems Hardware and Software Characteristics for the Marine Air/Ground Intelligence System (MAGIS)*, (Navy, 1975d).

Development of the system has been going on since 1965. Developmental and operational testing of two of the system's segments has been reported by:

1. *Testing of Complex Man/Machine Intelligence Systems: A Case Study Perspective of TIPI (MAGIS) Past, Present, and Future*, (Harrison, 1976).

2. *Segment Test Plan for the Intelligence Analysis/ Storage and Retrieval Category II Test Segments of the TIPI System/MAGIS*, (Systems Development Corporation, 1974).

3. *Final Report of the Imagery Interpretation (II) Segment Development Test and Evaluation/Initial Operational Test and Evaluation for the TIPI/MAGIS System*, (Texas Instruments, 1975).

The projected operational employment concepts for the system when it is fielded have undergone an evolutionary process during the system development (GE, 1972, 1974a; Navy, 1973b). This evolution of the Marine Corps' operational employment concepts, coupled with a greater understanding of the overall systems problem as indicated by *Utilization of Modular Equipment within the MAGIS Development Program*, (Navy, 1973e), led to a major revision in the systems-acquisition approach outlined in *Request for Change to Program Memorandum #50*, (Navy, 1975c). The development-program modifications necessary to implement the revised employment concepts and systems-acquisition approach were affected by policy changes within both the Air Force and Marine Corps (Air Force, 1975; Navy, 1975c).

The problems of the systems-development program leading to the revision of the Marine Corps' employment concepts, the analysis of these problems, and the headquarters-level decisions to revise the acquisition approach based on the analysis are the key elements of the problem studied here. The development and use of a systems-engineering team to address the systems-acquisition program was essential to the resolution of this problem. The team specifically assisted

the Marine Corps' top-level management in preparing for the major-decision Milestone II. Studying the development effort associated with the MAGIS acquisition program may motivate the employment of such a team in research and development (R&D). Therefore, the following three subjects will be covered in this chapter:

1. The background of the systems-development program.

2. The period in development when the program suffered from the lack of a systems-engineering approach.

3. The period in the development effort when the program benefited from systems-engineering approach.

There are several reasons why the MAGIS development program has been selected as an example. First, from February, 1972 to August, 1975, the author was the Development Project Officer for this joint development program and the senior Marine officer working full-time on the program. Second, the program is a large, complex, and costly ($300 million cumulative total) program that now involves all four services. Third, the documentation to carry out the analysis effort is readily available. Fourth, and most important, a systems-engineering team, operating in the mode discussed in the previous chapter, was employed to assist the top-level decision makers in the Marine Corps in addressing a Defense systems-acquisition problem.

Background of the Systems-Development Program

The Marine Air/Ground Intelligence Systems (MAGIS) is being developed as a tactical intelligence-processing system for use by the Marine Air/Ground Task Forces (MAGTF) in amphibious warfare. The Assistant Chief of Staff, Intelligence (G-2) of the amphibious landing force is responsible for providing the intelligence needed for command decisions. To discharge his responsibilities, the G-2 must be able to produce accurate, complete, timely, and useful intelligence during each phase of the amphibious operation. MAGIS is being developed to provide this capability through automated assistance to combat-intelligence activities. This will include automated assistance to what has historically been considered the special (i.e., electronics) intelligence function. The inclusion of this function will make the system *all-source*[1] and enable it to integrate data from a wide-range intelligence collection means.

The system will be capable of being transported by air, ground, and sea. It will be housed in a set of 8'X 8'X 20' steel shelters with a modern array of communications and data-processing capabilities. The incentive for developing a a system of this type was an imbalance that developed between the Marine Corps' information-collection capability and the intelligence-processing capability. In recent years the

[1]*All-source* is the ability to receive all types of intelligence data, including special intelligence.

Marine Corps' information-collection capabilities have been significantly increased by the use of remote sensors, aerial reconnaissance, and the monitoring of selected enemy electromagnetic radiations (Layne and Jorgenson, 1974). During the same period of time, the Marine Corps' ability to process, evaluate, and analyze information has remained relatively constant. These factors led to an imbalance between the collection capabilities and the processing capabilities where in the inputs produced by the former were restricted as throughput by the latter. The goal of the system development is to correct this imbalance and to support the amphibious-landing-force commander and subordinate commanders in their decision making processes.

In 1963, the Commandant of the Marine Corps (Navy, 1963) directed the development of an integrated air/ground intelligence system to be known as MAGIS. At the direction of DOD (Defense, 1964) a joint service program under the executive management of the Air Force was established to develop a tactical intelligence-processing system for all four services. Initially the Army and Navy simply monitored the development effort, but in recent years, they have become more closely associated. The Army will participate in the production buy for one of the systems' segments (Air Force, 1978), and the Navy will use the software designed for another segment to replace its existing Naval Intelligence Process System aboard certain classes of its ships (Navy, 1979). The program remains

a joint effort under Air Force executive management with personnel and R&D funding being contributed by the Marine Corps and the Air Force. Currently the Development Center, Marine Corps Development and Education Command, Quantico, Virginia, represents the Marine Corps in the development effort and is the contact point for all matters concerning MAGIS.

The classical intelligence cycle is made up of four phases: direction, collection, processing, and dissemination (see DELTA chart, Figure 33. MAGIS will support several segments of this development cycle with the necessary maintenance and logistical capabilities; however, the program *emphasis* for MAGIS is to develop a system to upgrade the *processing* of intelligence. Certain benefits will also be derived from the system for other phases of the intelligence cycle. Currently, the Marine Corps has various collection assets[2] to produce inputs for a manual processing system. The various stages of processing result in finished intelligence products, such as, estimates of enemy capabilities and summaries of previous enemy activities. MAGIS should upgrade the existing manual techniques for processing, thereby substantially increasing the effectiveness of intelligence production.

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[2] Collection assets are the capabilities by which raw information is collected from the battlefield. Examples of collection assets are tactical units in contact with the enemy, electronic monitors, reconnaissance aircraft, and infrared sensors (Navy, 1974c).

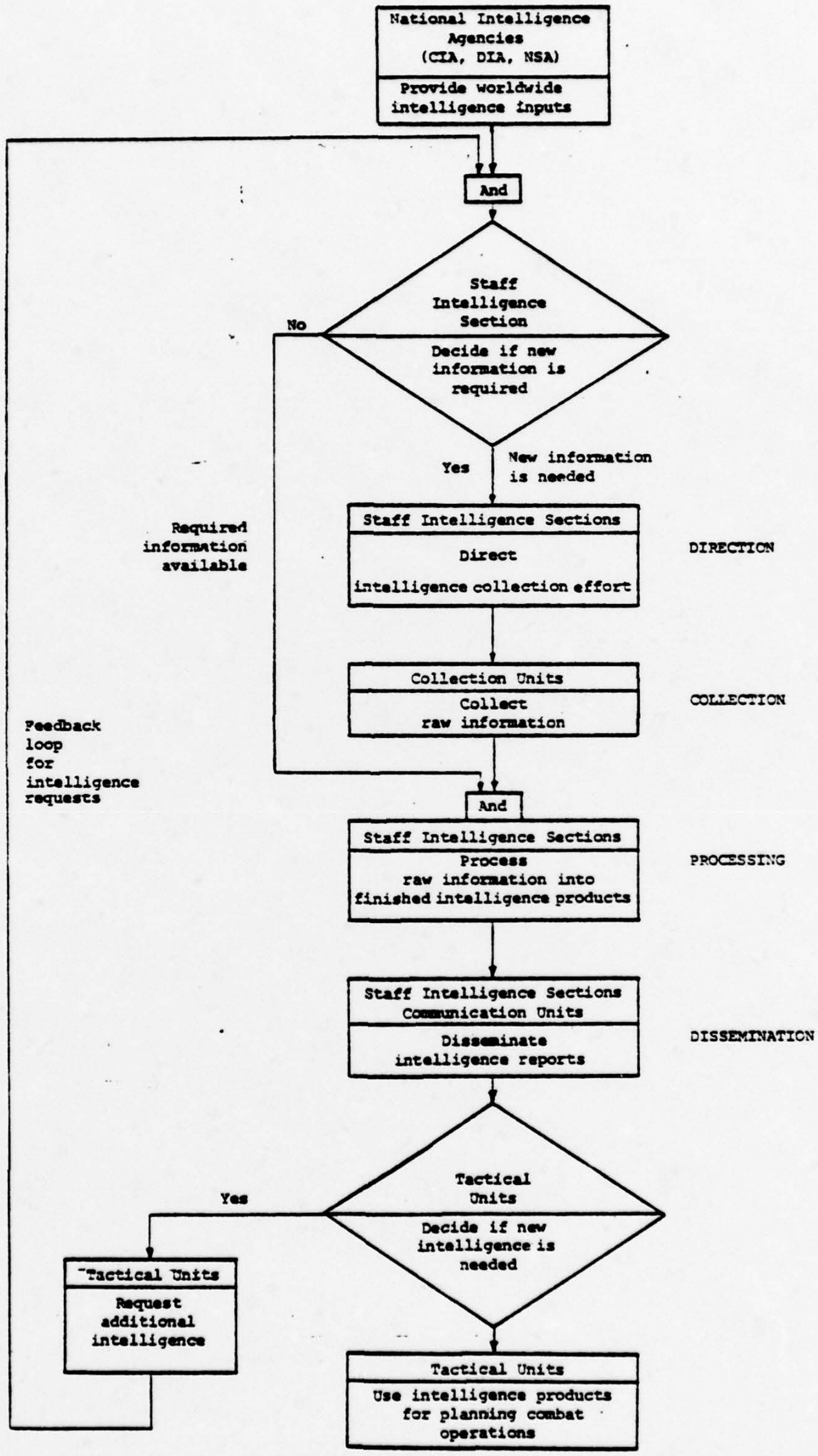

Figure 33. The Intelligence Cycle.

The nature of the overall intelligence cycle may be better understood if it is viewed as an input-output process. In this context, the collection effort provides the inputs (raw information); the finished intelligence is produced in the processing phase and distributed in the dissemination phase. The overall process is graphically presented in Figure 34. This figure portrays the collection of raw information and the processing of this information by all-source intelligence analysts to produce finished intelligence products.

The Period in Development When the Program Suffered from the Lack of a Systems-Engineering Approach

In 1964, the DOD designated the Air Force the executive agent for the joint service program and established the Tactical Information Processing and Interpretation Program Office (TIPI PO) to manage the program. The TIPI PO is part of the Electronic System Division of the Air Force Systems Command, located at L. G. Hanscom Field, Bedford, Massachusetts. The systems-program office received policy guidance from Headquarters United States Air Force and operational requirements from the Air Forces' Tactical Air Command. Based on its designation as the DOD system-program office, TIPI PO could directly manage and execute the development program, thus making it the focal point for the Air Force's involvement in the joint service program.

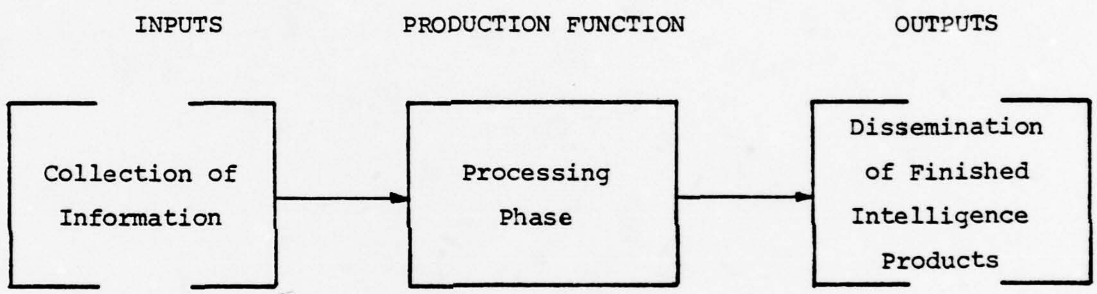

Figure 34. Intelligence Production as an Input/Output Process.

In the early years of the program, the Marine Corps' involvement in the program was somewhat more diffused than the Air Force's. Both Headquarters Marine Corps, and the Development Center, Marine Corps Development and Education Command (MCDEC) were involved in managing the Marine Corps' participation in the effort. Operational requirements evolved from the Development Center and the Marine Corps Operational Commands. Figure 35 graphically portrays this situation prior to 1972 with interactions between various Marine Corps activities and the TIPI program office. Partially because of this diffusion of responsibilities, several different subsystems or segments were identified in the early 1970's as separate operational requirements under the overall MAGIS umbrella (Navy, 1978). The full titles of these segments, their acronyms, and a brief description of their functions are presented in Table 10.

The first two segments noted in the table, Imagery Processing and Tactical Electronic Reconnaissance Processing and Evaluation, were to be up-grades of existing capabilities. The third segment, Imagery Interpretation, was newly developed to analyze imagery from the services' photographic reconnaissance aircraft.

The final three functional segments listed in the table, the Remote Input/Output System (RIOS), the Signal Intelligence/Electronic Warfare Coordination Center (S/EWCC), and the Intelligence Analysis/Storage and Retrieval (IA/SR), are

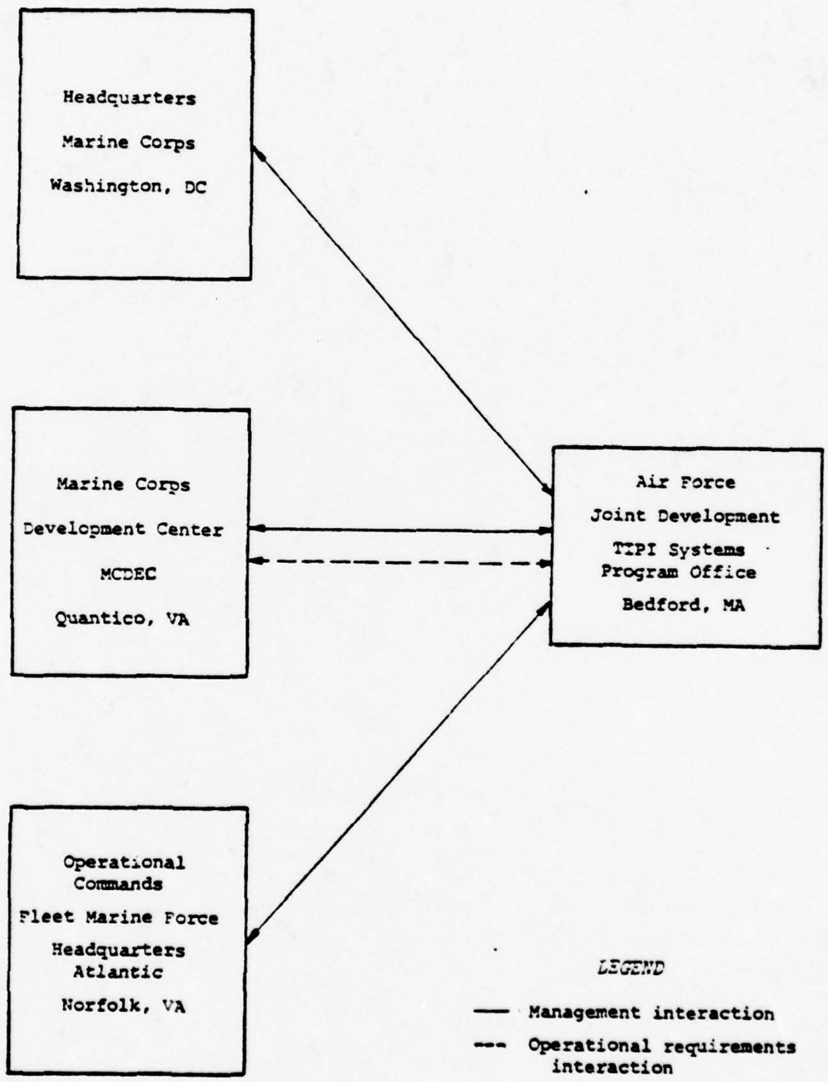

Figure 35. Diffusion of Development Responsibilities Within the Marine Corps for the MAGIS Systems-Acquisition Program prior to 1972.

TABLE 10

FUNCTIONAL SEGMENTS OF THE MARINE AIR/GROUND INTELLIGENCE SEGMENTS IN 1972

Long Title	Acronym	Function
Imagery processing	IP	Development and duplication of photographic materials
Tactical electronic reconnaissance processing and evaluation	TERPE	Processing capability for the identification and location of enemy electronic emitters
Imagery interpretation	II	Analysis of imagery for intelligence purposes
Remote input/output system	RIOS	Processing of all intelligence, except special, at the Marine division and wing levels
Signal Intelligence Electronic Warfare Coordination Center	S/EWCC	Special intelligence production and signal intelligence electronic warfare coordination at the Marine amphibious-force level
Intelligence analysis, storage, and retrieval	IA/SR	Processing of all intelligence, except special, at the Marine amphibious-force level

of the most interest in the context of this historical analysis. The RIOS was intended to provide an intelligence-processing capability to the Marine Division and Marine Aircraft Wing levels (Navy, 1972c). The S/EWCC was intended to provide a special (i.e., electronics) intelligence-processing capaibility to the Marine Amphibious Force level (the overall headquarters for the wing and division team)(Navy, 1970). One of the principal factors motivating this segment was the Marine Corps operational policy requirement to separate special intelligence from other types of intelligence. The IA/SR was intended to provide an intelligence-processing capability to the Marine Amphibious Force level (Navy, 1969a; Navy, 1969b). All three of these segments were to have similar functions related to processing of intelligence; only the type of data and the command level at which they operated were to differ. The S/EWCC and RIOS were unique Marine Corps operational requirements in the overall systems-development program.

In 1972, all three of these segments were under development, but each in a different phase of the systems-acquisition process and each by a different contractor. The RIOS was in the requirements-definition (mission-analysis) phase at General Electric Company in Daytona Beach, Florida; the S/EWCC was in the conceptual phase at the Bunker Ramo Corporation in West Lake Village, California; and the IA/SR was in full-scale development at the Systems Development

Corporation in Hampton, Virginia. This final segment was scheduled for development, test, and evaluation (DT&E) and for initial operational test and evaluation (IOT&E) in 1975. RDT&E funds of $30 million had been committed to this program to develop, test, and evaluate one preproduction model for the Air Force and one for the Marine Corps. In accordance with a memorandum of agreement between the U. S. Air Force and the Marine Corps (July, 1973), the Marine Corps provided a prorated share of these funds amounting to $6.5 million. However, newly identified operational requirements (i.e., compatibility with the Navy's tactical-intelligence data base) and essential software improvements necessitiated an additional expenditure of $1.2 million in funding for this segment. The S/EWCC and the RIOS had a combined total of $4.5 million tentatively programmed for the development of preproduction models to be used for DT&E/IOT&E (Navy, 1972b). There was significant concern within the Development Center of the Marine Corps Development and Education Command that the programmed funds for the S/EWCC and RIOS segments would be grossly insufficient to accomplish the projected development. A conservative estimate of the actual funds required was $5 million for each segment, for a combined total of $10 million.[3]

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[3]This estimate was based on the Marine Corps' contribution to the IA/SR preproduction-model (full-scale) development, which had cost little more than the systems hardware and had not included such things as the engineering design and software-development efforts. Later analysis efforts within the development center of MCDEC projected RDT&E costs of $4.8 million and $8.5 million for the RIOS and S/EWCC segments, respectively (Navy, 1973a).

During 1972 the overall status of the MAGIS development program was somewhat uncertain. There were three contractors in three separate locations carrying out development efforts for three different segments. Each development effort was intended to provide the Marine Corps with approximately the same type of functional and technical capabilities to process tactical intelligence. The potential problems listed below were inherent in carrying out parallel developments to acquire basically the same type of operational capability.

1. The development plans during this period projected the expenditure of substantial funds for what, in many respects, was redundant development.

2. The hardware components for each segment would, most likely vary considerably, which would require several different maintenance and support approaches for the system. The Marine Corps did not have sufficient resources to support several different approaches once the system was deployed.

3. The software developed for each segment would probably be different, requiring multiple training programs for system operators or different operators for each segment. Either alternative was incompatible with the Marine Corps' constrained manpower resources.

4. The separate development of three parallel segments made interoperability problems for the overall system inevitable once the system was fielded. For example, the intelligence data base and the communication protocols for

the segments differed, precluding the interchange of the information the system was being developed to process.

5. The development of so many different segments, (six are listed in Table 10) needed a global operational concept for fielding the overall system. The lack of these operational concepts, which did not exist in 1972, foretold of significant problems when the Marine Corps' combat units in the field would have to employ the system.

6. The development of three parallel segments and the substantial RDT&E funds ($10 million would be a conservative estimate) required, implied that top-level decision makers in the Marine Corps were not fully cognizant of the overall systems-acquisition process associated with the MAGIS program. Ultimately, the lack of understanding or top-level management support could have led to the failure of the program.

The means by which the above-mentioned potential problems were addressed is discussed in the next section.

The Period in Development When the Program Benefited from a Systems-Engineering Approach

In the previous section, the problem of the diffusion of development responsibilities for the MAGIS program within the Marine Corps was discussed. During 1972 this problem was corrected by Headquarters Marine Corp (HQMC). The fiscal year 1973 (FY-1973) RDT&E Work Directive for Magis (Navy, 1972b) stated, in part, that

> The Commanding General, Marine Corps Development and Education Command (MCDEC), Quantico, Virginia, will manage all aspects of the MAGIS development...on matters relating to Commandant of the Marine Corps (CMC) policy, program funding, and operational system developments, the Commanding General, MCDEC, will obtain CMC guidance and/or concurrence.

This directive clearly gave the responsibility for managing the MAGIS acquisition program to the Commanding General of MCDEC except in those areas where the decision process touched upon CMC policy matters. This management responsibility included planning and controlling the R&D funds for the program. Figure 36 portrays this new situation with MCDEC as the focal point for MAGIS development. Management and operational requirements interactions with HQMC and the Fleet Marine Force, respectively, were conducted through MCDEC to the Air Force TIPI Program Office.

Within the Marine Corps Development and Education Command, the Development Center and specifically, the Intelligence Division of the Development Center was asked to carry out the MAGIS acquisition program. A separate branch, the Automated Intelligence Systems Branch, was established within the Intelligence Division of the Development Center to address the MAGIS program. Initially this branch consisted of the branch head (or MAGIS Project Officer) and two other people, none of whom had been formally educated in systems engineering or had previously worked in a systems-engineering group. The need to develop a multidiscipline engineering team to address the MAGIS acquisition program was identified in October 1972.

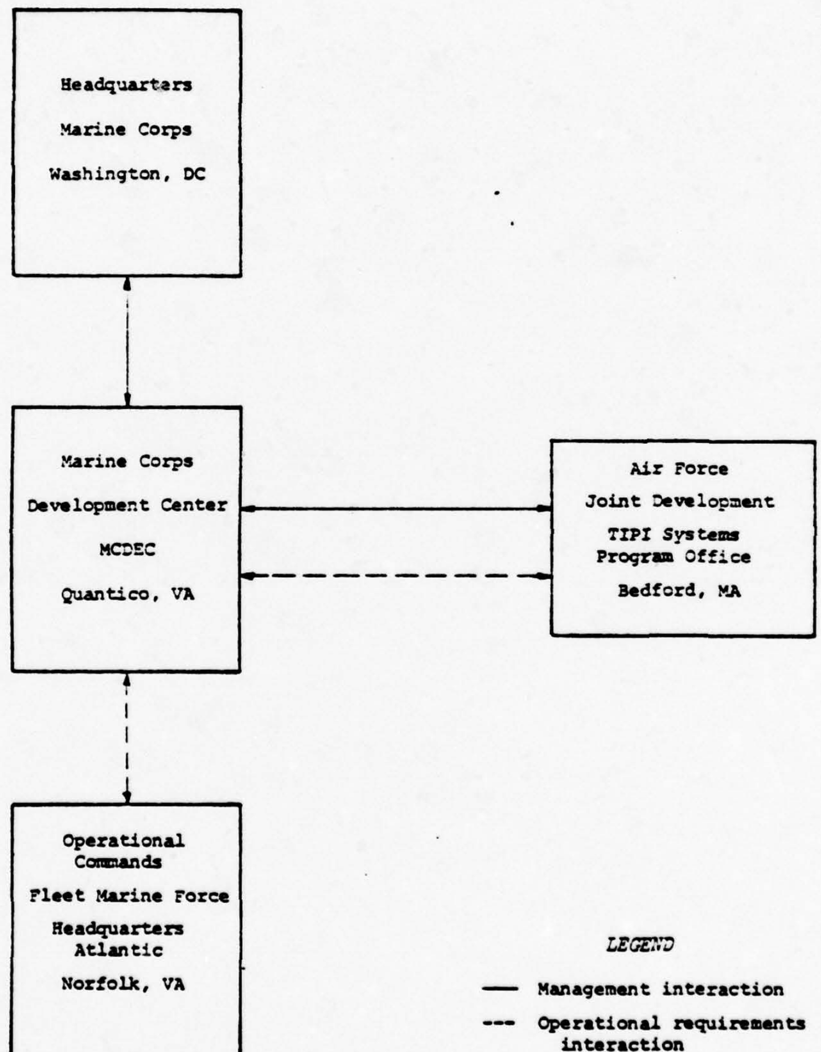

Figure 36. Centralization of Development Responsibilities within the Marine Corps for the MAGIS Systems-Acquisition Program after 1972.

This need was documented by the Chief of the Intelligence Division of the Development Center (Navy, 1972a) and stated,

> The Development Center is currently involved in a highly technical program for the development of MAGIS. This development effort cuts across a *multitude of technical disciplines.* However, the technical expertise needed to most effectively address and solve the developmental problems is not presently available for allocation against the technical R&D requirements....[Therefore] it is recommended that the Development Center take appropriate action to establish an *engineering support group* for the development of MAGIS.

In November, 1972, the Director of Naval Laboratories, Department of the Navy, the Director of the Development Center, and representatives of Headquarters Marine Corps were briefed on the need for multidiscipline-engineering support for the MAGIS program (Navy, 1975b). As a result, two civil service technical positions (one GS-14 electrical engineer and one GS-13 computer scientist) were established for the MAGIS program within the Intelligence Division of the Development Center. Several military officer positions, requiring a graduate education, were also reassigned to the MAGIS program. Ultimately, the multidiscipline engineering team grew to a total of eight people, including the team leader, the MAGIS Project Officer.

This MAGIS project officer, a major in the Marine Corps, held a bachelor's degree in mechanical engineering and a Masters in operations research and had previous management, operational, and analyst experience. He reported directly to the Chief of the Intelligence Division, Development Center, a colonel in the Marine Corps. The team leader managed the

overall activities of the team and had full authority, in addressing the problems associated with the MAGIS acquisition program, to allocate the resources of the team. The team leader and the team were charged, through the RDT&E Work Directive for MAGIS (Navy, 1978), with the following responsibilities,

1. Act as Marine Corps point of contact for all TIPI-Program Office matters of interest to the Marine Corps concerning the development, testing, and reporting of the TIPI/MAGIS project.
2. Continuously study and appraise the phases of MAGIS development, procurement, testing, and reporting to include:
    a. Maintain close direct liaison with TIPI-Program Office and provide the necessary operational guidance to insure that individual members of that office and their contractors know and understand Marine Corps MAGIS requirements,
    b. Maintain liaison with other service and commercial organizations on matters relating to TIPI/MAGIS development,
    c. Ensure that all operational requirements and other required documentation for MAGIS are provided to TIPI-Program Officer.

Five members of the team had graduate-level education. Several disciplines were represented on the team, including electrical engineering, computer science, mathematics, communications engineering, data-systems management, systems analysis, operations research, humanities (English), and mechanical engineering. All members of the team, except the two civil service employees, had extensive operational experience within the Marine Corps. Seven members of the team had previously held managerial positions at several levels in a variety of organizations; six members had prior R&D experience; and three

members of the team had been formally trained as analysts. Comparing the characteristics and functions outlined in Chapter 4 for systems-engineering teams and the characteristics and responsibilities outlined above for the MAGIS team, a systems-engineering team had obviously been formed to address the MAGIS acquisition program.

The systems-engineering team for the MAGIS program was formed within the Development Center of the Marine Corps Development and Education Command located at Quantico, Virginia. Following the suggestions in the methodology implementation section (p. 244) of Chapter 4, the systems-engineering team should be located within the R&D-staff section of service headquarters. Because the Marine Corps Development Center had been given the responsibility to manage the MAGIS program and limited Marine Corps manpower resources would not permit duplication of the function at the headquarters level, the MAGIS systems-engineering team could not be located as recommended in Chapter 4. However, the MAGIS systems-engineering team did functionally *bridge the gap* as described in Chapter 4, between the various analysis and engineering groups and the decision makers and policy makers. The team was able to have an impact on the decision making and policymaking process at the level of Headquarters Marine Corps. This team's opportunity to act in the role came about for several reasons. First, the management of the Development Center gave the team every opportunity to interface

with the principals involved with the program at Headquarters Marine Corps. Second, a team of this type did not exist at Headquarters Marine Corps and the Development Center's MAGIS systems-engineering team conveniently filled this void. Finally, the principal managers involved with the MAGIS program at Headquarters Marine Corps were very receptive to working with the team on a direct and personal basis.

The MAGIS systems-engineering team was to be initially concerned with the engineering and technical aspects of system development (Navy, 1972a). However, the scope of the team's responsibilities was quickly broadened to include operational considerations, recommended revisions to Marine Corps Policy, and support of the overall systems-acquisition decision process, including the Marine Systems Acquisition Review Council ([M]SARC) proceedings. From January, 1973, until August, 1975, the MAGIS systems-engineering team carried out many of the general functions and methodology-associated tasks outlined in Chapter 4 for such teams. A representative set of these functions and tasks are described below:

1. *Establishment of the Requirements Baseline.* The MAGIS systems-engineering team assisted in establishing the requirements-definition baseline and operational concepts for the system. This effort was carried out by the team's working closely with the several contractor analysis groups assigned to the program. The contractor and government analysis groups included Texas Instruments, working on the Imagery

Interpretation Segment; General Electric, on the Remote Input/ Output System segment; Systems Development Corporation, on the Intelligence Analysis Storage and Retrieval Segment; Bunker Ramo Corporation for the Signal Intelligence Electronic Warfare coordination Center; Naval Missile Center, Point Mugu, California, on the Tactical Electronic Reconnaissance Processing and Evaluation Segment; and the TIPI Program Office, working on the overall system. The many varied products of these analysis groups were synthesized by the MAGIS systems-engineering team and conveyed to the Development Center managers and the principals at HQMC primarily concerned with the program. This was done by holding a number of working sessions with the Director of Intelligence HQMC; Deputy Director Intelligence HQMC; Chief of Staff of the Development Center; and the MAGIS systems-engineering team. Throughout these working sessions, there was a free interchange of ideas and concepts related to operational requirements, system-employment procedures, and development approaches.

These working sessions resulted in the development of a document entitled, *MAGIS Development and Operational Concepts* (Navy, 1973b). It included operational and development concepts for each segment, interactions between the system segments, a system-depolyment concept, a system-maintenance concept, a system-communications concept, a set of constraints on system development and employment, and a plan to acquire each segment. Most work required to develop this document

was carried out by the MAGIS systems-engineering team. This effort had many facets that are analogous to the analysis required to develop what is now called the Mission Element Need Statement (MENS) for systems-acquisition programs. Additionally, much of the analysis effort required to develop the MAGIS Development and Operational Concepts was similar to that required to carry out Task #1 of the systems-engineering methodology outlined in Chapter 4 (p. 189).

2. *Development of an Alternative Candidate Solution for the Systems-Development Problem.* The MAGIS systems-engineering team developed a new alternative candidate solution for the systems-development problem. This solution addressed the problem of the apparent parallel development of three of the MAGIS segments--the Remote Input Output System segment, the Intelligence Analysis Storage and Retrieval Segment, and the Signal Intelligence Electronic Warfare Coordination Center segment. As noted in *The Period in Development When the Program Suffered from the Lack of a Systems-Engineering Approach* (p. 275), these three separate MAGIS functional segments were being developed to meet the same intelligence-processing requirements at various deployment levels.

The Intelligence Analysis Storage and Retrieval (IA/SR) segment was to be deployed at the Marine Amphibious Force echelon for the atuomated processing of combat intelligence. The Remote Input Output System segment was to perform the same function at the Marine Air Wing and Marine Division

echelons. Finally, the Signal Intelligence/Electronic Warfare Coordination Center (S/EWCC) segment was to provide automated processing of special intelligence (i.e., electronics). This development approach created interoperability problems between the various segments of the system. It also increased both development and procurement costs since each operational function and deployment echelon was considered separately.

The development, by the MAGIS systems-engineering team, of a new alternative candidate solution for the system depended on the analysis of the operational requirements discussed above. This analysis led to several significant conclusions:

1. That the three segments previously mentioned (IA/SR, RIOS, and S/EWCC) differed significantly only in the types and volumes of data processed by each segment and the particular command level at which the segments operated.

2. That the differences in data were related to security considerations for handling special intelligence data in the collection and direction phases of the classical intelligence cycle (see Figure 32).

3. That the projected technical capabilities (hardware, software, and means of communications) for each segment were basically the same.

4. That except for the security requirements to separate special intelligence data from other types of intelligence data, it was possible to design a single segment that would meet all three operational requirements.

Based on the above conclusions, the MAGIS systems-engineering team developed the *Modularity Concept* as an alternative candidate solution to resolve the problem of the parallel-segment developments (Navy, 1973e). One part of the modularity concept is stated as follows:

> That a single processing capability be developed based on a systems approach which will have the ability to:
>
> a. Handle several levels of throughput;
>
> b. Address a variety of functions;
>
> c. Support multiple command echelons.

This alternative candidate solution was to use the Intelligence Analysis/Storage and Retrieval (IA/SR) segment as the design baseline for a single processing capability to replace the previously mentioned three segments. It was to be housed in two distinct shelters (8'X 8'X 20'): One shelter was designed as an automatic data-processing/communications capability and the other was designed to house four analysts to process the all-source intelligence data. Depending on the throughput requirements of the system, additional analyst shelters could be added to the system, hence the term *modular concept*. This new single-processing capability was to be called the Intelligence Analysis Center (IAC). Figure 37 depicts the combining of the three intelligence-processing segments existing in 1972 into the single IAC capability.

The development of a new alternative candidate solution by the MAGIS systems-engineering team is an example of a systems-engineering team's performing its general function

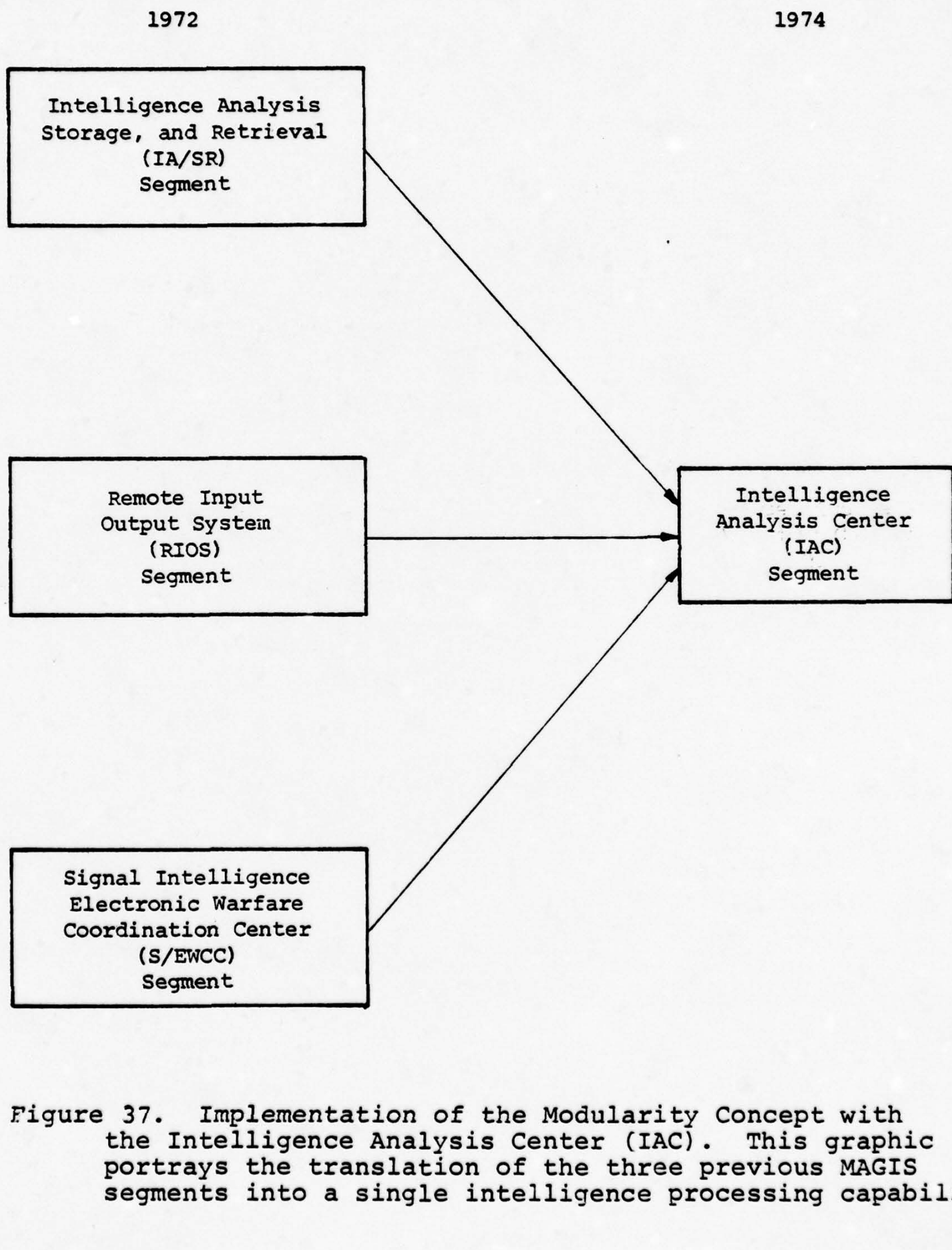

Figure 37. Implementation of the Modularity Concept with the Intelligence Analysis Center (IAC). This graphic portrays the translation of the three previous MAGIS segments into a single intelligence processing capability.

to *carry out critical analysis procedures that have major policymaking or decision-making significance to the organization* (see Chapter 4, p.246). Although this alternative candidate solution was developed in 1973 by the MAGIS systems-engineering team, the idea had to be approved by top-level decision makers before it could be implemented. The team's effort to secure this approval is the next example of the team's employment.

3. *Evaluation of the New Alternative Candidate Solution and Communications with Policymakers and Decision Makers.* Once the modularity concept of a single intelligence-processing capability (the Intelligence Analysis Center) was developed by the MAGIS systems engineering team, it had to be evaluated for possible implementation. This analysis was carried out jointly by the MAGIS systems-engineering team and a General Electric analysis group attached to the Air Force TIPI Program Office. Different evaluation factors were considered in relation to the IAC alternative candidate solution, including RDT&E and procurement costs, maintenance and training requirements, personnel requirements, management effort, policies and procedures relating to the handling of special intelligence, system supportability and interoperability. The results of these analysis efforts are presented in *Remote Input Output System (RIOS) Design Trade-off Analysis Report, Systems Integration and Checkout Contract, for the TIPI System* (GE, 1973); *Utilization of Modular*

Equipment within the MAGIS Development Program, (Navy, 1973e), and *Budgetary Estimates of the Marine Air/Ground Intelligence System (MAGIS) Equipment Development and Procurement* (Navy, 1973a).

The data developed during the 1973 analysis may be conviently presented using a technique documented in De Neufville and Stafford (1971). This technique is called an impact-incidence matrix and is designed to inform decision makers about the distribution of the benefits and costs of an alternative. The analyst can summarize the several measures of effectiveness associated with a particular alternative on a single table, such as that shown in Table 11. By using the same format for all competing alternatives, comparisons are facilitated. A summarization of the data developed as a result of the 1973 analysis for the IAC alternative candidate solution is presented in Table 12. In pursuit of the goal of brevity of this dissertation a more detailed analysis is not presented.

Subsequent to the evaluation of the IAC alternative, it had to be presented to top-level policymakers and decision makers for review and possible approval. This was done through several working conferences between Development Center and Headquarters Marine Corps personnel. Initially, a set of conferences were held with the Director of Intelligence and his staff at Headquarters Marine Corps to brief the Director of Intelligence on the operational policy implications and

TABLE 11

PROTOTYPICAL IMPACT-INCIDENCE MATRIX

Groups Impacted		Impacts			
		Directly Estimated $	Indirectly Estimated $	Estimated Numerically not in $	Estimated Qualitatively in words
		a_1 a_2 a_3 ...	b_1 b_2 ...	c_1 c_2 ...	d_1 d_2 ...
Directly	A_1				
	A_2				
	.				
	.				
	.				
Indirectly	B_1				
	B_2				
	.				
	.				
	.				
Special interests	C_1				
	C_2				
	.				
	.				
	.				

SOURCE: de Neufville and Stafford (p. 249, 1971)

NOTES: The vertical axis represents the groups impacted by a particular alternative; the horizontal axis represents measures of effectiveness by which the costs and benefits of a particular alternative are evaluated.

TABLE 12

IMPACT INCIDENCE MATRIX FOR THE IMPLEMENTATION OF THE IAC

Groups Impacted	Impacts		
	Reduction of Estimated Costs	Quantifiables	Nonquantifiables
Headquarters Marine Corps	Procurement $12.2 M (+)	Less management time required with the single program (+)	Revision required in policy directives (-) Special intelligence security clearances needed for more personnel (-)
Development Center	RDT&E $ 9.0 M (+)	Less analysis and R&D effort required with the single program (+)	Other R&D programs should benefit from additional time and resources saved from MAGIS program (+) Revision required in the MAGIS requirements baseline (-)
Operational Commands Marine Corps	Total $21.2 (+)	Maintenance and operational personnel will be reduced (+) Personnel training requirements will be reduced (+) Fewer repair components will have to be stocked (+) Maintenance support equipment will be reduced (+)	Revision required in operational and procedural directives (-) System will perform multiple functions at all major command levels (+) System interoperability will be improved (+) Tactical intelligence products will be improved by the input from special intelligence sources (+) System will be more supportable (+)

NOTES: Data presented in this table use the existing three MAGIS segments as a baseline for comparison; (+) represents a benefit, (-), a cost; benefits for the IAC alternative are presented in *Utilization of Modular Equipment within the MAGIS Development Program* (Navy, 1973e); cost estimates were adapted from *Budgeting Estimates for the Magis Equipment Development and Procurement* (Navy, 1973a) based on an analysis for the MAGIS systems-engineering team

employment opportunities that would result from implementing a single intelligence-processing capability, or IAC. The technical ramifications of implementing the IAC development approach were presented by members of the systems-engineering team. Detailed discussions were held on the need to revise the Marine Corps' operational policy relating to the security requirements for handling special intelligence if the IAC development approach was to be implemented. As a direct result of these discussions, official approval was given to revise Marine Corps' operational policies for the handling of special intelligence thus paving the way for the implementation of the IAC development approach (Navy, 1973d).

Discussions were also held with the Deputy Chief of Staff, Research and Development, Headquarters Marine Corps and representatives from other staffs at Headquarters Marine Corps. The MAGIS systems-engineering team members presented material on different topics that had been analyzed by the MAGIS team, including the IAC development approach. Again as a direct result of discussions, Headquarters Marine Corps' official approval was given to begin designing the IAC (Navy, 1973c). Figure 37 is a graphical representation of the three previous MAGIS segments being translated into a single intelligence-processing capability, the IAC. Throughout the conferences discussed above, the MAGIS systems-engineering team performed its general function to *translate*

the results of internal analysis efforts into management information (see Chapter 4, p. 246).

4. *Communication of Policy Guidance From Headquarters to the Analysis Groups Working on the Program.* When the Headquarters Marine Corps' policy guideline (Navy, 1973c, 1973d) was issued for the IAC development approach, the MAGIS systems-engineering team had to convey this policy guidance to the analysis groups working on the program. The members of the team worked closely with representatives of the TIPI Program Office to insure that the Air Force Development Agency for MAGIS understood the newly defined Marine Corps' operational policy. Detailed working sessions were held with the separate TIPI Program Office sections to properly identify the many ramifications of implementing the new policies for handling special intelligence.

The MAGIS systems-engineering team also worked closely with the intital design contractor for the IAC segment, the General Electric Company. The team members had to establish the new requirements for handling special intelligence and the single intelligence-processing capability in much greater detail than in the two Marine Corps policy and decision letters for the IAC segment. The end product of this effort was the *Summary Technical Report for the Intelligence Analysis Center (IAC) Segment for the MAGIS*, (GE, 1974a). This document detailed the compression of the three previous MAGIS segments into the single intelligence-processing

capability of the IAC and included relevant design information on the special-intelligence-handling requirement. Table 13 lists the MAGIS development segments in 1974 after the initial adoption of the IAC as a single intelligence-processing capability.

Throughout the working sessions discussed above, the MAGIS systems-engineering team performed its general function *to keep the analysis groups informed of policy revisions that could impact analysis procedures* (see Chapter 4, p.246).

5. *Development of Evaluation Areas and Factors.* Once the Intelligence Analysis/Storage and Retrieval (IA/SR) design was approved as the IAC segment baseline, the Marine Corps would have to consider a full-scale development phase for the IAC. During the full-scale development phase, a test model IAC would be designed and built for development test (DT) II and initial operational test and evaluation (IOT&E). Before going to full-scale development, the Marine Corps had to consider major-decision Milestone II. Major-decision Milestone I was waived;[4] the strong design baseline that had evolved out of the previous IA/SR segment development was

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[4]The Intelligence Analysis/Storage and Retrieval (IA/SR) segment, the IAC design baseline, was then (1974) in the full-scale development phase. This design baseline represented an alternative candidate solution that had been approved at major-decision Milestones I and II for the IA/SR program and had successfully completed the conceptual and demonstration-and-validation phases. Therefore, the IAC systems-acquisition program did not have to be subjected to major-decision Milestone I. This had been effectively accomplished in the IA/SR program.

TABLE 13

FUNCTIONAL SEGMENTS OF THE MARINE AIR/GROUND INTELLIGENCE SEGMENTS IN 1974 AFTER ADOPTION OF THE IAC

Long Title	Acronym	Function
Imagery processing	IP	Development and duplication of photographic materials
Tactical electronic reconnaissance processing and evaluation	TERPE	Processing capability for the identification and location of enemy electronic emitters
Imagery interpretation	II	Analysis of imagery for intelligence purposes
Intelligence Analysis Center	IAC	Processing, collation, and evaluation of all-source intelligence at all levels

regarded as the demonstration and validation phase for the IAC program.

In preparing for the major-decision Milestone II, the MAGIS systems-engineering team worked with Development Center Management and Headquarters Marine Corps personnel developing overall evaluation areas and factors to be considered. Development and production costs, development risk, supportability of the system in the field, technical performance characteristics, and overall development schedules were all evaluated. Each area was thoroughly analyzed to determine specific evaluation factors to be used in the major milestone II decision process. Factors similar to those persented in Table 9 (Evaluation Areas and Factors, p.209) were developed. During this same time, the MAGIS systems-engineering team updated the constraints and goals for the IAC development program. These constraints and goals were documented in a letter from the Commanding General of MCDEC to the Program Manager of the TIPI Program Office (Navy, 1974b).

In doing the analyses, the MAGIS systems-engineering team performed several functions analogous to those required to implement Task #3 (p. 218) for the systems-engineering methodology developed in Chapter 4.

6. *Assistance in Defining the Major Milestone II Decision Problem and in Evaluating Alternative Candidate Solutions.* In preparing for the major-decision Milestone II

(or Marine [M]SARC II); the MAGIS systems-engineering team worked closely with Headquarters Marine Corps' personnel to define the decision problem. The key issue in the acquisition program at this time was which development approach (alternative candidate solution) should be used for the full-scale development phase of the Intelligence Analysis Center (IAC). This issue related primarily to the equipment to be used in developing the IAC.

The baseline design for the IAC, the Intelligence Analysis/Storage and Retrieval (IA/SR) segment, had been developed using minicomputers, the AN/UYK-12. The Air Force TIPI Program Office supported the development of the IAC using these minicomputers. On the other hand, the Marine Corps had recently directed that the AN/UYK-20, the Navy-standard minicomputer, be used within the Marine Corps. The Navy had also developed peripheral equipment adapted to the Navy-standard AN/UYK-20 minicomputer. Several factions within the Marine Corps supported the development of the IAC using the AN/UYK-20 and its peripheral equipment. The IAC was a unique Marine Corps development program and the Marine Corps was funding the RDT&E and production costs. Therefore, the issue of which equipment package to use was resolved within the Marine Corps and the Air Force was requested to implement the decision.

Prior to the (M)SARC II decision point, a number of analysis groups considered what suite of equipment should

be used in the IAC acquisition program for the full-scale development phase. General Electric Company, the Systems Development Corporation, the TIPI Program Office, and the Naval Surface Weapons Center, Dahlgren, Virginia, all analyzed the problem. The MAGIS systems-engineering team reviewed the results of these analysis efforts, synthesized their results, and developed a background document on the problem. The Deputy Chief of Staff, Research and Development, Headquarters Marine Corps was then briefed in August, 1974. At that time, he directed that the matter be referred to a Headquarters Marine Corps In-Progress Review Committee, which consisted of several other general officers. Before presentation to the review committee, the MAGIS systems-engineering team was directed to develop the life-cycle costs (LCC) for the system with both alternatives--of developing the IAC with the AN/UYK-20 or the AN/UYK-12 minicomputers (Navy, 1974d).

The MAGIS systems-engineering team performed the IAC-segment life-cycle-cost (LCC) analysis during August and September of 1974 with the aid of a FORTRAN computer model originally developed by the General Electric Company (GE, 1974b) but revised by the MAGIS systems-engineering team. The analysis arrived at a cost for the RDT&E, production, and operations for the two separate alternatives. These figures were forwarded to Headquarters Marine Corps from the Development Center (Navy, 1974d).

On October 3, 1974, the Headquarters Marine Corps' In-Progress Review Committee met to consider the IAC systems-acquisition program. This committee meeting was a precursor to the (M)SARC II decision point. The Committee considered three principal factors in deciding which alternative candidate solution should be used in the IAC full-scale development phase (Navy, 1974a): the Marine Corps standardization program for minicomputers, life-cycle costs of the systems, and the logistic and maintenance supportability of the system in the field. The last two factors had been subjected to extensive analysis by the MAGIS systems-engineering teams. The In-Progress Review Committee was briefed on four alternative candidate solutions for the IAC development program. Different MAGIS team members addressed various aspects of the decision process. The life-cycle cost analysis, in particular, became a critical factor in the decision process. Ultimately, the committee decided to make a formal recommendation to the (M)SARC II panel that the IAC be developed using the AN/UYK-20 minicomputer and its associated peripheral equipment (Navy, 1974a).

In performing the above services, the MAGIS systems-engineering team did much of the analysis required to support major-decision Milestone II as projected by Task #3 (p. 218) of the systems-engineering methodology outlined in Chapter 4. The MAGIS team also carried out the following

general systems-engineering team functions as outlined in Chapter 4:

a. Translate the results of internal analysis efforts into management information;

b. interpret the results of other organizations' analyses for management;

c. carry out critical analysis procedures that have major policymaking or decision making significance to the organization.

7. *Assistance in the Preparations for the Marine (M)SARC II Presentations.* Much of the analysis described in the previous example was revised and updated by the MAGIS systems-engineering team to support the (M)SARC II proceedings for the IAC segment. Prior to the meeting, members of the MAGIS team attended conferences and working sessions to prepare Headquarters Marine Corps personnel for the (M)SARC II decision milestone. The general systems-engineering team's tasks and functions, as described above under 6., were carried out by the MAGIS team to prepare top-level management for major-decision Milestone II. These efforts culminated in the decision by the (M)SARC panel of general officers to implement the IAC full-scale development phase using the AN/UYK-20 minicomputers (Navy, 1975a,b).

The following benefits were credited to the employment of the MAGIS systems-engineering teams from January, 1973, to August, 1975:

1. Two systems-acquisition programs were completely deleted from the Marine Corps' operational requirements when the three previous MAGIS segments were combined into the Intelligence Analysis Center (IAC) segment.

2. Savings conservatively estimated at $9.0 million for RDT&E and $12.2 million for production were realized when adoption of the modularity concept, developed by the MAGIS team and adopted by the Marine Corps, caused a conservatively estimated reduction in the RDT&E and production budgets of $9.0 million and $12.2 million. The impact of these reductions may be realized by comparing the Marine Corps' total RDT&E budget of approximately $30-40 million a year for that period to the total minimum savings of $21.2 million.

3. The Marine Corps potential interoperability problems because of the three different segments existing in 1972 were eliminated by establishing the single intelligence-processing capability, the IAC.

The benefits above resulted from the employment of the MAGIS systems-engineering team and, particularly, the role the team played in the decision process as outlined in the seven example activities described in this section. A graphic summary of the activities of the MAGIS systems-engineering team from February, 1973, to August, 1975, is presented in Figure 38. This figure portrays the team in the role that it performed *to bridge the gap* between

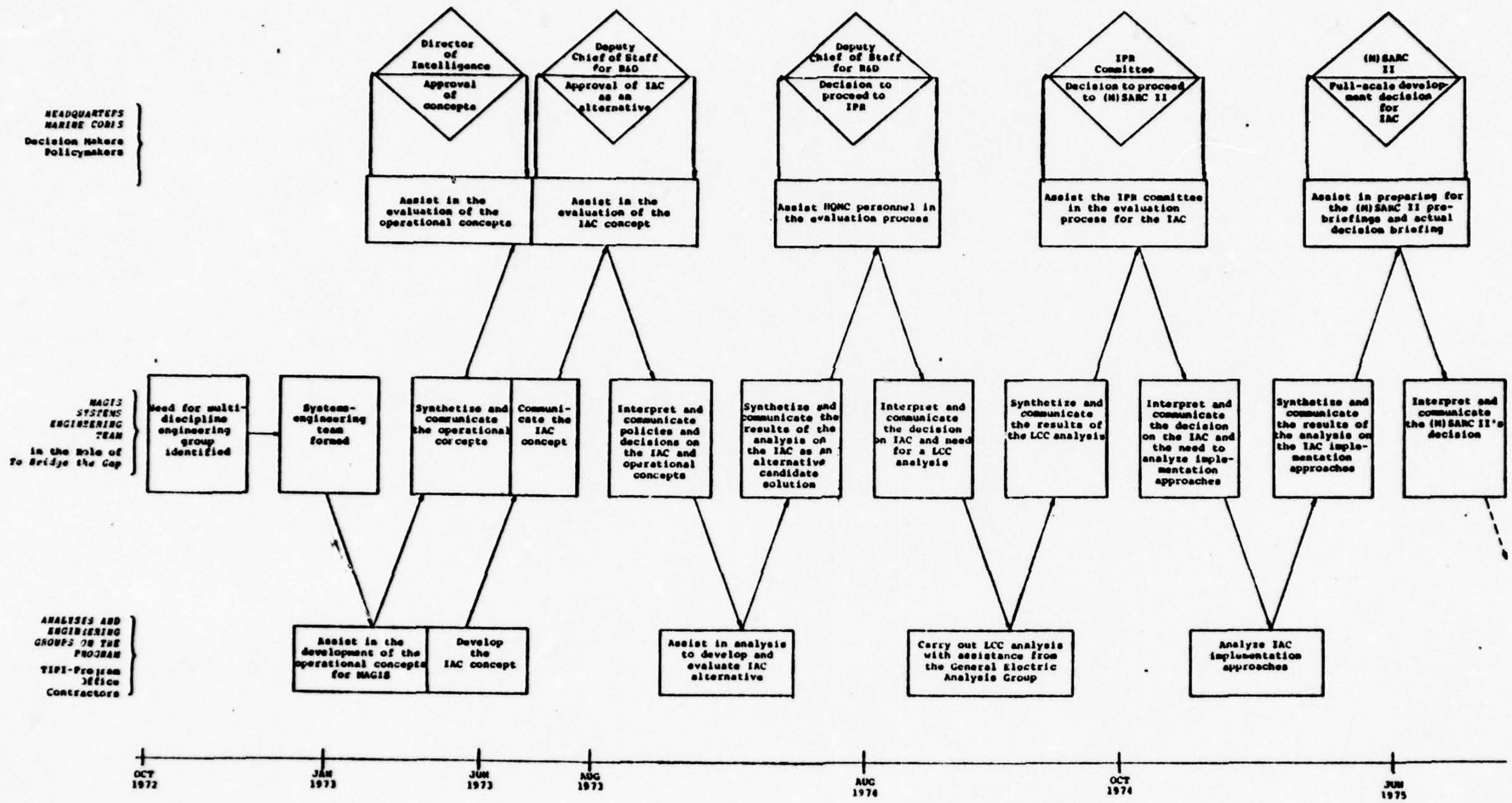

Figure 38. Interaction of MAGIS Systems-Engineering Team with Headquarters Marine Corps and Analysis Groups for the Intelligence Analysis Center Program.

policymakers and decision makers and the various analysis and engineering groups working on the program.

Summary and Conclusions

This chapter addressed a real-world Defense systems-acquisition program and its associated decision process. A joint development effort between the Marine Corps and the Air Force to develop a computer-based system for processing tactical intelligence was studied from a historical prospective. Specifically, this program was examined to determine how the employment of a systems-engineering team and approach impacted the system-development program and associated decision process.

First the chapter provided sufficient historical and background information on the program to establish a framework within which the specific systems problems could be studied. Second the period of the development when the program suffered from the lack of a systems-engineering approach was studied. Some problems from this period of the development effort were redundant development efforts, excessive costs, ill-conceived operational concepts, and a lack of insight into the systems problems by top-level management within the Marine Corps. This chapter also covered the period of development when the program benefited from a systems-engineering approach. It was during this period that a systems-engineering team was formed and used to support

the decision process as the systems-development program approached the major Milestone II decision point. Throughout this period, the systems-engineering team worked closely with both the Marine Corps' decision makers and the various analysis and engineering groups working on the program. Therefore based on the material developed in this chapter, the following conclusions are drawn:

1. That the MAGIS program is representative of a Defense systems-acquisition program to which a systems-engineering approach could be applied.

2. That a systems-engineering team, possessing the general team characteristics as described in Chapter 4, was formed to assist in the decision process associated with the MAGIS development program.

3. That the systems-engineering team that was formed carried out several of the general functions and the methodology-associated tasks outlined in Chapter 4 for such teams. The following functions and tasks were performed by the team:

a. Assisted in establishing the requirements-definition baseline and operational concepts for the system.

b. Developed a new alternative candidate solution for the systems-development problem based on a clearly defined set of operational requirements.

c. Assisted in evaluating the new alternative candidate solution (technical approach) and communicated the

nature of this new alternative to policymakers and decision makers. The team also assisted them in understanding the operational policy implications and employment opportunities that would be associated with implementing the new technical approach. These efforts resulted in a new operational policy for the employment of the system in the field.

d. Assisted in communicating the Headquarters Marine Corps' operational policy guidance, which would impact systems development, to the various analysis and engineering groups working on the program.

e. Assisted in the development of evaluation areas and factors that would enable discrimination between the alternative candidate solutions during the major-decision Milestone II process.

f. Assisted the Marine Corps' decision makers in defining the decision problem and in evaluating and selecting the alternative candidate solutions at the Milestone II decision point.

g. Assisted in the preparations for the actual (M)SARC presentations for the Milestone II decision point.

4. That based on the comments outlined above in 3., the systems-engineering team associated with the MAGIS development program acted *to bridge the gap* between policy makers and decision makers and the various analysis and engineering groups working on the program.

5. That the systems-engineering team substantially contributed to the improvement of the MAGIS development program by:

a. Assisting in the development and adoption of a more viable set of operational employment concepts for the system.

b. Assisting in the redirection of the overall systems-development program, which resulted in significant cost savings during the full-scale development phase of the systems-acquisition process.

c. Assisting decision makers and policymakers in more effectively handling their responsibilities.

d. Assisting engineering and analysis groups working on the program to better understand policy guidelines from the Headquarters Marine Corps level.

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Chapter 6

SUMMARY, CONCLUSIONS, CONTRIBUTIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

Summary

This research effort investigated the management of the systems-acquisition process within the Department of Defense (DOD). It indicated how the DOD could apply systems-engineering techniques to achieve a more effective approach to decisions involved in the development and procurement of Defense systems.

Initially, a review was presented of the evolution of DOD acquisition policies and procedures over the last several years. The existing policy structure for the systems-acquisition process was then analyzed with emphasis on the phases, activities, and decisions of the process. The phases and activities of the systems-acquisition process were then compared, respectively, to the various phases and steps of the systems-engineering framework. There was a respective pairwise relationship between the phases, activities, and discipline requirements of the systems-acquisition process and the phases, steps, and knowledge requirements of the systems-engineering framework.

Using the systems-engineering framework, the nature and structure of the Defense systems-acquisition decision process was examined to identify analysis areas where the

application of a systems-engineering methodology would be most beneficial. Selection criteria and organizational considerations were identified for choosing appropriate systems-engineering tools and techniques for use in the methodology. A methodology with several specific analysis tasks was then developed. The analysis procedures associated with these tasks were dependent on the particular *stage* of the acquisition process and the nature of the decision under consideration. Implementation of the methodology was discussed next. In this portion of the effort, particular emphasis was placed on the formation and proper utilization of systems-engineering teams to support policymakers and decision makers in carrying out their responsibilities. The functions and characteristics nominally associated with these systems-engineering teams were presented.

Finally, a historical analysis was presented of a Defense systems-acquisition program. The program analyzed was oriented toward the development of a tactical intelligence system. The principal thrust of this analysis was to demonstrate the viability and usefulness of employing both a systems-engineering approach and team in supporting the Defense systems-acquisition decision process.

Conclusions

Based on the material developed in this systems study, several conclusions may be drawn. Four major conclusions are presented here in priority order.

1. The systems-acquisition process may be effectively modelled by a systems-engineering framework. The two are similar in that there is a respective pairwise correlation between the phases and steps of the framework and the phases and activities of the process. Additionally, both the systems-acquisition process and systems engineering are multidisciplinary activities.

2. The systems-acquisition process could benefit from the application of a systems-engineering methodology to support (1) the problem definition in the mission-analysis phase and (2) the major-decision milestones of the process. The analysis techniques selected as procedures in the methodology should be dependent on both organizational considerations and the stage of the development program under evaluation.

3. Effective implementation of the methodology is critically dependent on the formation and proper use of systems-engineering teams working with top-level managers within the Office of the Secretary of Defense and the several service headquarters. The principal role for these teams is that of *bridging the gap* between policymakers and decision makers and the various analysis and engineering groups working on the program. In this role, they can significantly enhance communications for the development programs and thereby improve the overall management of the systems-acquisition process. These improvements would be reductions in research, development, test and evaluation, and

production costs and in development time; they would enhance supportability and interoperability once the system is deployed.

4. The systems-engineering team associated with the Marine Air/Ground Intelligence System (MAGIS) development program (selected for historical analysis) *bridged the gap* between Marine Corps Headquarters (policy and decision makers) and the several analysis groups working on the program. The employment of the systems-engineering team in this role provided substantial benefits to the Marine Corps from 1972 to 1975 and is a good example of the successful application of the methodology, which is the subject of this dissertation.

Contributions

The contributions of the research to the systems-management component of systems engineering are identified as follows:

1. It establishes that the systems acquisition process may be appropriately modelled by the systems-engineering framework and demonstrates the applicability of the systems-engineering tools and techniques to the activities of the process.

2. It demonstrates how the systems-acquisition decision process may be supported by the application of the systems-engineering-methodology tasks to the major-decision milestones.

3. It provides systems-acquisition decision makers and policy makers a means by which they can enhance their managerial abilities--the formation of the systems-engineering

team, as discussed, and the use of these teams in the roles described for them.

4. It demonstrates the usefulness of the systems-engineering approach and the role of systems-engineering teams in the Defense systems-acquisition process by considering an applied problem.

5. It establishes a foundation for the future study of the systems-acquisition process throughout the federal government.

Recommendations for Future Research

Several recommendations for future research suggest themselves:

1. Apply the systems-engineering methodology and associated analysis procedures developed in the research to a variety of active Defense systems-acquisition programs.

2. Extend the systems-engineering-methodology tasks to other activities of the DOD systems-acquisition process.

3. Establish criteria to determine the applicability of a systems-engineering methodology to the systems-acquisition process within other federal agencies.

4. Develop a specific systems-engineering methodology to support the systems-acquisition decision process in other federal agencies, such as, the Department of Transportation or the Department of Energy.

5. Develop a global systems-engineering methodology to support the systems-acquisition decision process for all federal agencies from the perspective of the Office of Federal Procurement Policy within the Office of Management and Budget.

6. Study the areas of interaction between the federal government and the industrial sector in relation to the application of a systems-engineering methodology to the systems-acquisition decision process.

APPENDIX A

LIST OF TECHNICAL TERMS

LIST OF TECHNICAL TERMS

The following is a list of definitions selected from many sources in the course of writing this dissertation and over several years of working in the field. They are included as an aid to the reader and in the interest of better communications.

Acquisition program. A directed effort funded either through procurement appropriations, or research, development, test, and evaluation appropriations with the goal of providing a new or improved capability in response to a validated need. An acquisition program may include either development or procurement of systems, subsystems, equipment, munitions, or modifications to them, as well as supporting equipment, systems, projects, and studies.

Acquisition risk. The chance that some element of an acquisition program produces an unintended result with an adverse effect on system effectiveness (technical risk), cost (cost risk), or availability for deployment (schedule risk). Risk could also be considered in relation to social, environmental and political factors.

Acquisition strategy. A general set of concepts for handling technical, business, and programmatic matters pertaining to the management of a major system. Plans provide the detailed methods for the fulfillment of the strategy.

Agency component. This is a major organizational subdivision of an agency. For example: the Army, Navy, Air Force, and Defense Supply Agency are agency components of the Department of Defense.

Agency missions. Those responsibilities for meeting national needs which are assigned to a specific agency.

Availability. A measure of the degree to which an item is in the operable and commitable state at the start of a mission when the mission is called for at an unknown (random) time.

Budgeting. For the purpose of planning, programming and budgeting system (PPBS): the process of determining short-range detailed allocation of resources to execute assigned missions.

Compatibility. The capability of two or more operational items/systems to exist or function as elements of a larger operational system or operational environment without mutual interference.

Conceptual phase. The period of the acquisition process which deals with the identification and exploration of alternative solutions or solution concepts to satisfy a validated need, ususally through the use of contracts with competent industrial and educational institutions. This phase requires the active involvement of all participating commands to identify the candidate solutions and their characteristics. One or more of the selected candidate solutions are then approved for entry into the Demonstration and Validation phase.

Constraint. A resource limitation which may be specific (e.g., the supply of skilled manpower of a particular type of a particular metal), or general (e.g., total available funds).

Cost analysis. A process employed to develop or assess the reasonableness and validity of resource requirement estimates for military systems and programs. This process includes a statement or report of the assessment together with related conclusions.

Cost-effectiveness analysis. The quantitative examination of alternatives prospective systems for the purpose of identifying the perferred system and its associated equipment, organizations, etc. The examination aims at finding more precise answers to a question and not at justifying a conclusion. The analytical process includes tradeoffs among alternatives, design of additional alternatives; and the measurement of the effectiveness and cost of the alternatives.

Critical issues. Those aspects of a system's capability, either operational, technical, or other, that must be questioned before a system's overall suitability can be known, and which are of primary importance to the decision authority in reaching a decision to allow the system to advance into the next phase of development.

Decision Coordinating Paper (DCP). The principal document to record essential system program information for use in support of the Secretary of Defense decision-making process at Milestones I, II, and III.

Defense Acquisition Executive (DAE). The principal advisor and staff assistant to the Secretary of Defense and the focal point in the Office of the Secretary of Defense (OSD) for systems acquisition.

Defense Mission. The mission of the Department of Defense (DOD) as specified by the legislative authority.

Defense Systems Acquisition Review Council (DSARC). An advisory body to the Secretary of Defense on major systems acquisition. The Council members are the OSD staff principals.

Demonstration and validation phase. The period of the acquisition process when selected candidate solutions are refined through extensive study and analyses; hardware development, if appropriate; tests; and evaluations. The objective is to validate one or more of the selected

solutions and give a basis for deciding whether to proceed into full-scale engineering development.

Deployment phase. The period of the acquisition process encompassing the process of uniting facilities, hardware and software, personnel and procedural publications; and delivering an acceptable integrated system to the using and supporting commands. This overlaps the production phase.

Design to cost (DTC). Management concept wherein rigorous cost goals are established during development and the control of systems costs (acquisition, operating, and support) to these goals is achieved by practical tradeoffs between operational capability, performance, cost, and schedule. Cost, as a key design parameter, is addressed on a continuing basis and as an inherent part of the development and production process.

Development Test I (DT I). This test is conducted early in the development cycle, normally during the validation phase. Components, subsystems, or the entire system are examined to determine whether the system is ready for full-scale development. State-of-the-art technology is addressed in DT I.

Development Test II (DT II). This test provides the technical data necessary to assess whether the system is ready for low rate initial or full-scale production. It measures the technical performance and safety characteristics of the item and evaluates its associated tools, test equipment, training package, and maintenance test package as described in the development plan. DT II addresses accomplishment of engineer design goals.

Development test and evaluation (DT&E). That test and evaluation conducted to assist in engineering design and development process and verify attainment of technical performance specifications and objectives.

Engineering change proposal. A proposal to the responsible authority recommending that a change to an original item of equipment be considered; and the design or engineering change be incorporated into the article to modify, add to, delete or supersede original parts.

Five year defense program (FYDP). The basic DOD programming document for the entire military establishment; an integrated, coordinated program of forces, costs, manpower, procurement, and construction projected over a four-year period beyond the budget year. The FYDP consists of summary tables supported by detailed submissions of the military departments and other DOD components. The FYDP is formally approved by the Secretary of Defense and is binding, for programming purposes, on all components of the DOD.

Full scale development phase. The period of the acquisition process when the system and the principal items necessary for its support are designed, fabricated, tested, and evaluated. The intended output is, as a minimum: a preproduction system that closely approximates the final product; the documentation needed to enter the production phase; and the test results that show the product will meet the requirements. This phase includes the procurement of long lead production items and limited production for OT&E.

Independent cost estimate. An estimate of program cost developed outside normal advocacy channels by a team which generally includes representation from Cost Analysis Procurement, Production Management, Engineering and Program Management.

Initial operational test and evaluation (IOT&E). That portion of operational test and evaluation conducted prior to the Milestone III decision.

Interoperability. The ability of systems, units, or forces to provide services to, and accept services from, other systems, units or forces, and to use the services so exchanged to enable them to operate effectively together.

Life cycle cost (LCC). The total cost to the Government of a system over its full life. It includes the cost of development, acquisition, operation, support, and where applicable, disposal.

Line authority. DOD officials in the direct chain of authority from the Secretary of Defense to the program manager and excluding staffs.

Logistics supportability. The degree to which adequate provisions can be made in system's acquisition for support and test equipment, supply support, maintenance manuals, technical data, and support facilities.

Maintainability. A characteristic of design and installation which inherently provides for an item to be retained in or restored to a specified condition within a given time, when it is maintained in accordance with prescribed procedures and resources.

Major systems acquisition. A system acquisition program designated by the Secretary of Defense to be of such importance and priority as to require special management attention.

Military operational requirements. The formal expression of a military need, response to which results in development or acquisition of items, equipments, or systems.

Mission area. A segment of the defense mission as established by the Secretary of Defense.

Mission element. A segment of a mission area critical to the accomplishment of the mission area objectives and corresponding to a recommendation for a major system capability as determined by a DOD Component.

Mission element need statement (MENS). A statement prepared by a DOD Component to identify and support the need for a new or improved mission capability. The mission need may be the result of a projected deficiency or obsolesence in existing systems, a technological opportunity, or an opportunity to reduce operating cost. The MENS is submitted to the Secretary of Defense for a Milestone 0 decision.

Mission need. A required capability which is within an agency's overall purpose, including cost and schedule considerations.

Operational effectiveness. The overall degree of mission accomplishment of a system used by representative troops in the context of the organization, doctrine, tactics, threat, and environment in the planned operational employment of the system.

Operational Test I (OT I). OT I is an operational test of a hardware configuration of a system, or components thereof to provide an indication of military utility and worth to the user. Testing should refine identified critical issues, report areas that should be addressed in future OT and identify new ones for subsequent testing. OT I is accomplished during the Validation Phase on brassboard configuration, experimental prototypes to provide data leading to the decision to enter Full-scale Engineering Development.

Operational Test II (OT II). OT II is the test of engineering development prototype equipment prior to the initial product decision. Its goal is to estimate an item's military utility, operational effectiveness, and operational suitability in as realistic an operational environment as possible. Test objectives are based on the critical issues which are best examined by using elements of/or complete TOE troop units in controlled field exercises.

Operational test and evaluation (OT&E). That test and evaluation conducted to estimate a system's operational effectiveness and operational suitability, as well as the need for any modifications. It is accomplished by operational and support personnel of the types and qualifications expected to use and maintain the system when deployed and is conducted in as realistic and operational environment as possible.

Planning. The selection of courses of action through a systematic consideration of alternatives in order to attain organizational objectives.

Planning, programming, budgeting system (PPBS). An integrated system for the establishment, maintenance, and revision of the FYDP and the DOD budget.

Pre-production model. An article in final form employing standard parts, representative of articles to be produced subsequently in a production line and capable of being operationally tested.

Production phase. The period of the acquisition process from production approval until the last system is delivered and accepted. The objective is to efficiently produce and deliver effective and supportable systems to the operating units. This includes the production of all principal and support equipment.

Program. An organized set of activities directed toward a common purpose, objective, or goal which are undertaken or proposed by an agency in order to carry out responsibilities assigned to it.

Program element. A description of a mission by the identification of the organizational entities and resources needed to perform the assigned mission. Resources consist of forces, manpower, material quantities, and costs as applicable. The program element is the basic building block of the FYDP.

Program evaluation review technique (PERT). A technique for management of a program through to completion by constructing a network model of integrated activities and events and periodically evaluating the time/cost implications of progress.

Program manager. The individual in the DOD chartered to manage a major systems acquisition program.

Program manager charter. A document approved by the DOD Component Head stating the program manager's responsibility, authority and accountability in the management of a major systems acquisition program.

Programming. The process of translating planned military force requirement into specific time-phased, scheduled actions, and of identifying in relatively precise terms the resources required. It is the bridge between planning and budgeting.

Program objectives. The capability, cost and schedule goals which are being sought by the systems acquisition program in response to a mission need.

Program objective memorandum (POM). A memorandum in prescribed format submitted to the Secretary of Defense by the Secretary of a military department of the Director of a defense agency which recommends the total resource requirements within the parameters of the published Secretary of Defense fiscal guidance.

Requirement. The need or demand for personnel, equipment, facilities, other resources or services, expressed in specific quantities for specific time periods.

Reliability. A fundamental characteristic of an item of material expressed as the probability that it will perform its intended function for a specified period of time under stated conditions.

Request for proposal (RFP). The solicited document between the Government and Contractor on a contemplated procurement. It is the medium by which a contractor is introduced to the job desired by conveying a complete understanding of the work to be performed and to determine the capability and price of the contractors efforts. Other forms of solicitation documents include the invitation for bid and Request for Quotation.

Risk assessment. The process of subjectively determining the probability that a specific interplay of performance, schedule, and cost as an objective, will or will not be attained along the planned course of action.

Survivability. The degree to which a system is able to avoid or withstand a man-made hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission.

Systems acquisition process. A sequence of specified decisions events and phases of activity directed to achievement of established program objectives in the acquisition of Defense systems. This process extends from approval of a mission need through successful deployment of the Defense system or termination of the program. The sequence of these decisions and phases are as follows:

Milestone	Decision	Phase
0	Program initiation	Conceptual
I	Demonstration and validation	Demonstration and validation
II	Full-scale engineering development	Full-scale engineering development
III	Production/deployment	Production & Deployment

(Service) systems acquisition review council ([S]SARC). The Council established by the Head of a military department as an advisory body to him and through him to the Secretary of Defense on major systems acquisitions. The (S)SARC is chaired by the Secretary/Under Secretary of the military department and is similar in functional composition, responsibilities and operation to the DSARC. In application the term (Service) is replaced by the designation of the applicable military department, i.e., ASARC (Army), DNSARC (Department of the Navy), AFSARC (Air Force), and (M)SARC (Marine Corps).

Standardization (NATO). The process by which NATO nations achieve the closest practicable cooperation among their forces; facilitate the most efficient use of research, development and production resources; and agree to adopt on the broadest possible basis the use of (a) common or compatible operational, administrative, and logistic procedures, (b) common, compatible or interchangeable supplies, components, weapons or equipment. (c) common or compatible technical procedures and criteria, (d) common or compatible tactical doctrine with corresponding organizational compatibility.

System design concept. An idea expressed in terms of general performance, capabilities, and characteristics of hardware and software which is oriented either to operate or to be operated as an integrated whole in meeting a mission need.

System program office. The office of the program manager and single point of contact with industry, Government agencies and other activities participating in the systems acquisition process.

Test criteria. Standards by which test results and outcome are judged.

Thresholds. Monetary, time, or resource limitations placed on a program, to be used as guides as the program progresses and the breaching of which is cause for careful review of at least some aspects of the program.

Vulnerability. The characteristics of a system which causes it to suffer a definite degradation (incapability to perform the designated mission) as a result of having been subjected to a certain level of effects in an unnatural (man-made) hostile environment.

APPENDIX B

PERSONNEL INTERVIEWED FOR THE DEPARTMENT OF DEFENSE SYSTEMS-ACQUISITION STUDY

PERSONNEL INTERVIEWED FOR THE DEPARTMENT OF DEFENSE SYSTEMS-ACQUISITION STUDY

Mr. David Anderson
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Program Manager (GS-14)
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Headquarters United States Marine Corps
Washington, DC 20380

Rear Admiral R. G. Freeman, III, USN
Commandant
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Former Deputy Assistant Secretary of Defense, Material Acquisition

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Lieutenant Colonel Robert B. Machen, USA
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Major General W. B. Maxson, USAF
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Major General Robert Scurlock, USAF
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Washington, DC 20330

Former Program Manager, F-15

Dr. A. L. Slafsosky
Scientific Advisor to the Commandant of the Marine Corps
Code RD
Headquarters United States Marine Corps
Washington, DC 20380

Colonel James A. Stempson, USAF
Chief Formulation and Analysis Division
Office of the Deputy Chief of Staff for Research and Development
Headquarters, Department of the Air Force
Washington, DC 20330

Captain Tommy J. Trask, USAF
Acting Executive Secretary to the Air Force SARC
Office of Management Policy
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APPENDIX C

INTERVIEW GUIDE FOR DEFENSE SYSTEMS ACQUISITION

APPENDIX C

INTERVIEW GUIDE FOR DEFENSE SYSTEMS ACQUISITION

Name:

Address:

Title:

Responsibilities:

1. Background on the current DOD Systems-Acquisition Process.

   a. What has been the major impact of Office of Management and Budget Circular A-109?

   b. How has the implementation of DOD directives 5000.1 and 5000.2 changed the systems-acquisition process?

   c. What revisions were required in your service's management of systems acquisition? Procedural? Organizational?

   d. What is the number of major systems-acquisition programs currently active in your service?

   e. How many (S)SARCs are held each year?

2. Nature of the (S)SARC and DSARC milestones. How do the characteristics of the four decision milestones differ considering the development programs?

   a. Consider risk and uncertainty?

   b. Consider cost?

   c. Considering the ability to meet development schedule?

   d. Considering interfaces with other systems?

   e. Considering insight into the ability of the system to meet operational requirements?

   f. Considering the strength of support for the system by various service factions?

3. Characteristics of the members of the (S)SARC or DSARC.

   a. Military vs. civilian backgrounds?

   b. Experience?

   c. Educational backgrounds?

      1. Technical backgrounds and academic levels?
      2. Top-level school graduates?

d. Are the positions as shown in the directives always represented on the panels?

4. Value system operative in (S)SARC or DSARC.

   a. Is the objective to increase national defense capabilities?

   b. Is the objective always to respond to the new or revised enemy threat?

   c. Is the objective to represent the interests of one's own organization or staff section?

   d. Is the objective to insure survival of the organization or one of its functions (for example, interservice rivalry)?

   e. Is the objective to push a particular technology and/or system as a supporting item for existing or follow-on developments?

   f. Is the objective to push a particular alternative because it is politically or financially feasible?

5. Preparations for the (S)SARC and DSARC.

   a. How is material to be presented developed?

   b. Who does the analysis?

   c. Who presents the material?

   d. Are several options presented? In priority order?

   e. What is the technical level of the presentations?

   f. Are the proceedings ever stopped and a request put out for further analysis and new information?

6. The decision process within the (S)SARC and DSARC.

   a. Are there cases where the decisions are will on the way to being set prior to the meetings?

   b. How much impact do the actual presentations have on the decision policy?

   c. Are options sometimes revised as a result of the discussions in the (S)SARC?

   d. Is there a voting process?

   e. Is the Chariman's vote the most important one?

   f. Are alternatives normally put into priority sequence or is only the "best" alternative shown on the decision paper from the Chairman?

7. The overall decision process for systems acquisition.

   a. What are the results when the (S)SARC positions are reviewed by the Service Secretary? Agreement? Minor changes? Total Revision?

b. Is the material presented to the DSARC similar in content to that presented to the (S)SARC? Are analysis, preparations, and presentation procedures the same?

c. Do the services tend to develop a single "service" position prior to the DSARC then brief only this single alternative?

d. What are the results when the DSARC positions are reviewed by the Secretary of Defense? Agreement? Minor changes? Total revisions?

8. Identify the differences between the policies for systems acquisition and actual practice within DOD.

a. Are there differences in the development, processing, and timing of documentation, such as, the DCP and MENS?

b. Are decisions sometimes made by other committees, groups, or persons external to the DSARCs and (S)SARCs?

c. How does the system handle decisions which may be driven by sources outside DOD, such as, the President or Congress?

d. Does the lobbying of contractors or other interest groups induce differences in the way a system is handled?

e. Are there other differences?